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The effect of a preconditioning program and biomechanical risk factors

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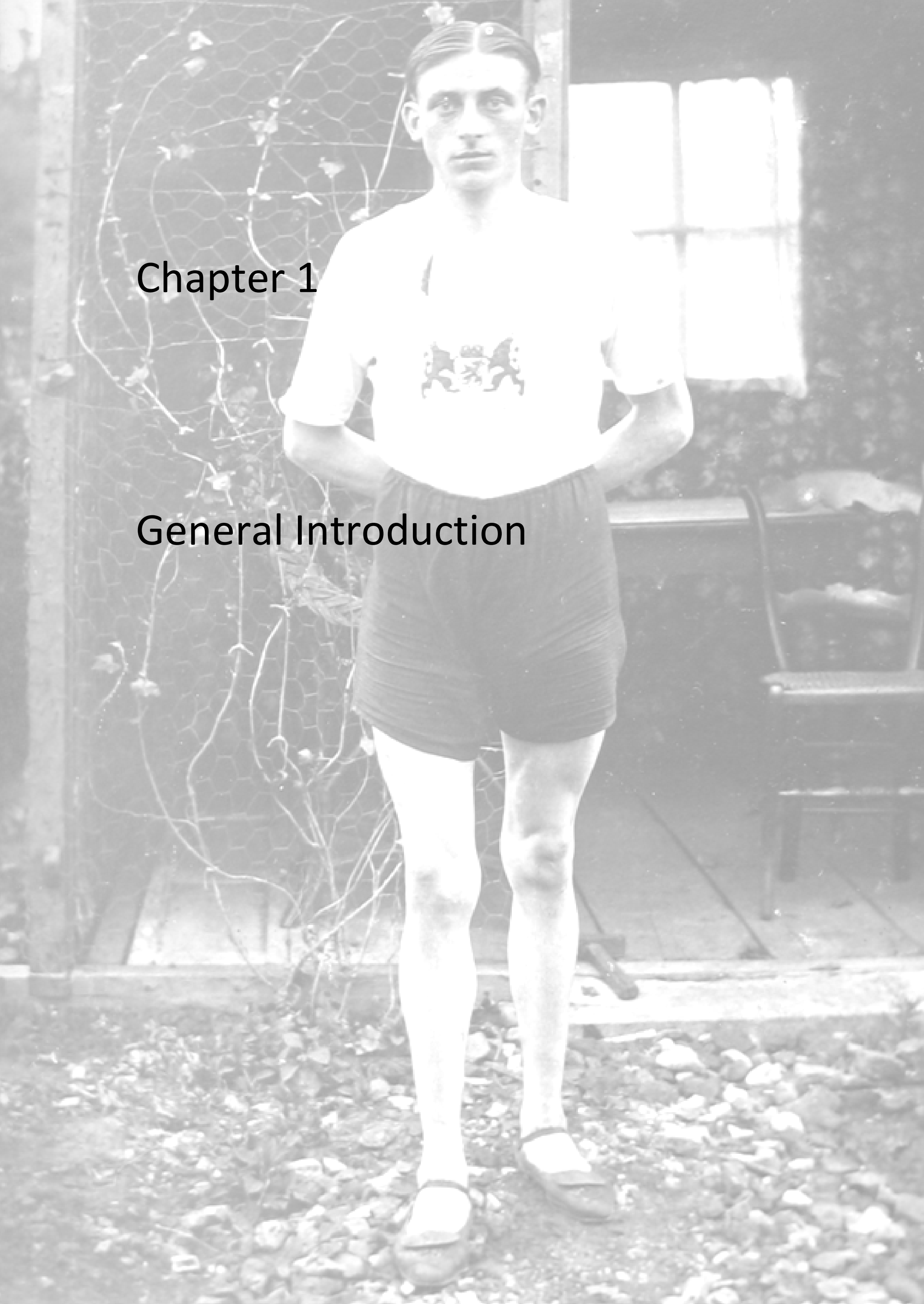
Chapter 1

General Introduction



Running has evolutionary roots and is therefore in our genes. The 'Evolution Marathon' began about 2 millions years ago. The area in which the pre humans lived was covered by dense forest, where chimpanzees gambolled through the branches eating sweet fruits. The climate changed to a dryer environment, the trees receded and open savannahs developed. The human race moved from a chunky chimplike movement pattern to our present characteristically bipedal movement strategy and human body shape with an upright position.[1,2] Around the same time, we started to eat meat, mostly by scavenging meat from carcasses. This protein rich food gave us the ability to develop more brain volume. Our body was changing with less hair and more sweat glands. In the open savannah the human race was able to hunt large animals in hot weather without the use of weapons. With this differentiating body we were able to walk and run, not to sprint, but a steady, persistent endurance running speed. Humans were unique in endurance running and could run long distances in hot and humid conditions. Most mammals ceased running because they could not cool their core body temperature and therefore were easy pray for the humans after a few hours of endurance running. This so called persistence hunting is an evolutionary advantage for the human race.[3] Without weapons, which only arrived around 200,000 - 50,000 years ago, the human race could out-compete other animals with persistence hunting, still apparently used in some cultures today.[3] From this evolutionary perspective running made us human. Since the inventions of weapons like spears and bow and arrow there is no need to run, but in young history running became important again for the human race. In 490 BC Pheidippides ran from the town of Marathon to Athens to bring news that the Greek army defeated the Persian army and dropped dead on arrival. Centuries later, in 1896, eighteen men competed in Athens in the first Olympic marathon. The winner finished in 2:58:50. In 1897 the oldest marathon of the world still organized was founded in Boston. The biggest marathon nowadays is the New York City marathon in which over 50,000 participants are competing every year. In the early days of the marathon only male competitive elite athletes were running. The average finishing time was around 3 hours. In 1980 ten percent of the marathon runners were female nowadays approximately forty percent of the marathon runners are female. The average finishing time of running a marathon has dramatically increased. The average finishing time for female athletes in the marathon is slightly above 5 hours and the average finishing time for male runners is 4 hours and 45 minutes. From this data it can be seen that marathon running has changed form an elite sport event to a mass recreational leisure event in which competing is more important than winning.

Nowadays running is one of the most popular forms of exercise for many adults.[4] The Royal Dutch Athletics Federation (KNAU) has estimated that around 12.5% (2 million people) of all Dutch citizens are running now-and-then, and that the popularity of running events is still growing.[5] This popularity of running positively contributes to increasing levels of physical activity in the population. This is important, because physical inactivity is associated with the development of several chronic diseases, decreased longevity, loss of physical function and weight control.[6] Running is a feasible way for people to become more active. To start with running, just a pair of shoes is needed.

Next to the positive effects of being physically active by running, there is also the possibility of a running related injury (RRI). In running, the incidence of RRI's is high.[7-13] The major reason for discontinuation (drop out) of a running program is injury.[14] Negative experiences, caused by an injury that occurs while training for a running event, have the potential to significantly affect the future physical activity of each individual.[15] It is also known that (fear of) sustaining an injury is associated with failure to start and maintain a physically active lifestyle.[15] So, prevention of injuries in novice runners is important.

Van Mechelen developed an injury sequence model to describe the different steps of efficient research on preventing sports injuries.[16] As can be seen in figure 1 four steps are described.

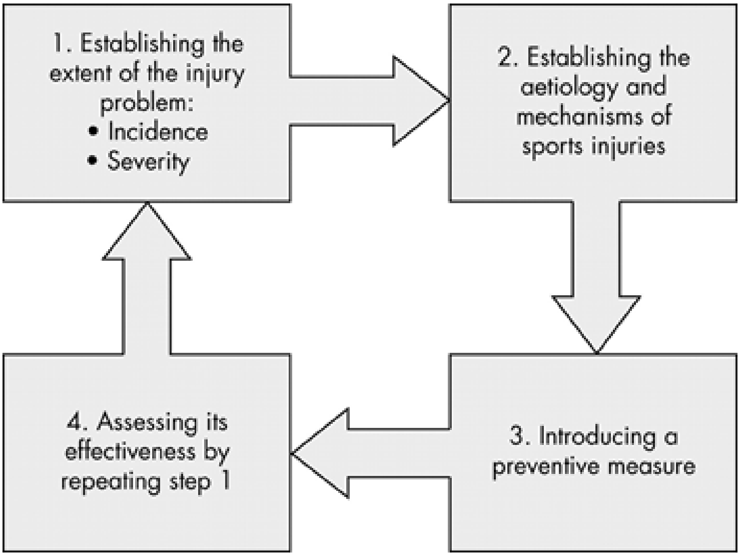


Figure 1. The injury sequence model of van Mechelen.[16] Reprinted with permission.

The first step is to establish the extent of the problem; in this thesis the incidence of running related injuries which is a mentioned before high. The second step is to look for (modifiable) risk factors. When a modifiable risk factor is identified an intervention can be developed to look for a preventive effect. When this intervention has been proven effective a new measurement can be done to establish the effect in the population at risk.

Finch added two steps to the injury sequence model of van Mechelen (figure 2) called the TRIPP model.[17] Is this model implementation and the measurement of implementation is added to ensure success in preventing injuries in terms of compliance, efficacy and effectiveness.

Model stage	TRIPP
1	Injury surveillance
2	Establish aetiology and mechanisms of injury
3	Develop preventive measures
4	"Ideal conditions"/scientific evaluation
5	Describe intervention context to inform implementation strategies
6	Evaluate effectiveness of preventive measures in implementation context

Figure 2. The Translating Research into Injury Prevention Practice (TRIPP) framework.[17] Reprinted form Elsevier 2006, with permission.

Most injuries in runners are overuse injuries of the lower extremity, caused by training errors i.e. running too much, too soon.[18] The exact cause and risk factors of RRI's are still unknown. However, it can be stated that the etiology of these injuries is multifactorial and diverse. A review by Van Mechelen19 proposed only four risk factors that have been significantly related to running injuries: a) lack of running experience, b) previous injury, c) running to compete, and d) excessive weekly running distance.

Observations from clinical studies have estimated that over 60% of running injuries could be attributed to training errors (too much, too soon).[18] Effects of warming up, cooling down and stretching are contradictory and inconclusive in the prevention of sports injuries.[19] Age, height, weight, body mass index (BMI), sex and fitness level have not been related to running injuries.[18,20] Other training variables such as shoes and training surface showed no causal effect on the risk of RRI's.[21-23] Several anatomical variables have been implicated as causes of overuse running injuries, including longitudinal arch structure of the foot, ankle range of motion, leg length discrepancies and lower extremity alignment. There is no consensus among researchers regarding the effect of these variables on overuse injuries.[8,19] Biomechanical variables such as excessive pronation, impact force, rate of force development and other kinetic and kinematic factors are studied, but no differences were found in relation to sustaining an RRI.[19,21,23]

The etiology of RRI's remains unclear and well designed studies using modifiable risk factors in the prevention of RRI's in competitive, recreational and novice runners are lacking. Until now, little high-quality research has been done into the prevention of running related injuries. Randomized controlled trials on the effect of interventions for preventing running injuries in recreational runners are scarce. Ten of the twelve randomized controlled studies found on the prevention of running injuries were not representing recreational runners.[20] The other two intervention studies drew runners from the general population, but did not include female runners in the final analysis.[20] Yeung et al. concluded in their Cochrane review: "…well controlled randomized controlled trials are needed to shed light on the possible interventions for the prevention of lower limb soft tissue injuries in runners".[20]

In preventive medicine it is important to develop interventions based on the understanding of the etiology and mechanisms of injury and the preventive intervention has to be acceptable, practical and adopted by athletes and sport bodies so that the implementation of the intervention can be successful.[17]

Another lack in the current literature are prospective studies looking for anatomical, training related or biomechanical risk factors.

The GRONORUN 1 study showed that previous sports participation without axial loading was an important risk factor for RRIs in novice runners.[24] From this knowledge an intervention was chosen to strengthen the lower extremity to achieve a positive physiological adaptation of the musculoskeletal system before starting a training program for novice runners. The applied external load of this so called preconditioning program will stress the lower extremity and as a result will positively adapt to the applied load. In this way there is a stepwise transition of biomechanical load which make it easier for the musculoskeletal system of the lower extremity to withstand the demands of running. It was hypothesized that this preconditioning program would decrease the number of RRIs in a group of novice runners.

From the point of view that external load in sporting activities could be a risk factor in the development of RRIs the effect of different kinetic variables on RRIs should be studied. There were no prospective studies looking for the effect of kinetic factors, such as vertical ground reaction forces, loading rate, impact peak and active peak on the incidence of RRIs.

In this thesis two important steps of the injury sequence model are described in the search for modifiable risk factors (step 2) and an intervention (step 3) to reduce the incidence of running related injuries in novice runners.

Therefore the aim of this thesis is to determine the effect of a preconditioning program on the incidence of RRIs in novice runners and to determine biomechanical risk factors of running related injuries in injured and noninjured novice runners.

In **chapter 2** an overview is given of what is known about risk factors and interventions in running related research. In **chapter 3** the design of a randomized trial is described to look for the effect of a preconditioning program on the effect of preventing RRIs in novice runners. In **chapter 4** the results of the effect of the preconditioning program are presented and discussed. In **chapter 5** an instrumented treadmill with embedded force transducers to measure vertical ground reaction forces in running is validated. The validation process was necessary because the custom made treadmill was not a gold standard to measure vertical ground reaction forces. The use of this treadmill is less time consuming compared to measurements in running laboratory with embedded three dimensional force plates. In **chapter 6** differences in vertical ground reaction forces between injured and noninjured novice runners are presented. In

chapter 7 results are presented looking at asymmetries in spatio-temporal and biomechanical factors in injured and noninjured novice runners. This thesis ends with c**hapter 8**, which provides a general overview of this thesis and discusses findings of these thesis as well as directions for future research.

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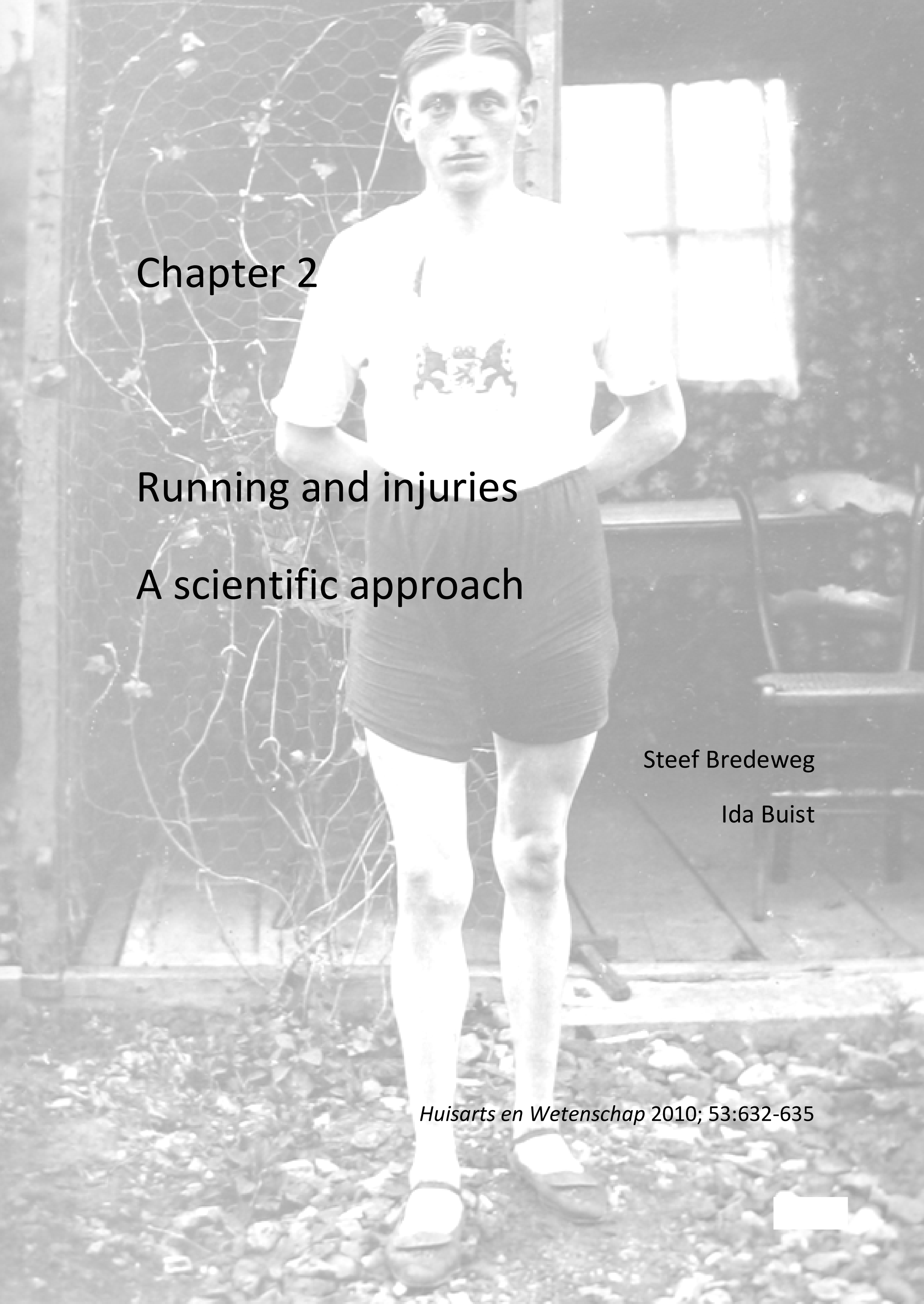

Chapter 2

Running and injuries

A scientific approach

Steef Bredeweg

Ida Buist

Huisarts en Wetenschap 2010; 53:632-635

Abstract

Running is a popular sport. In the Netherlands over 2.5 million people are running regularly. Running is a healthy activity, is easy to do and can be done everywhere. On the other hand when more people are starting to run there are more running related injuries (RRIs). Every year 20 to 75% of all runners are injured. These figures vary because of different populations, the definition of an RRI, the duration of the studies and the follow up. Most RRIs are overuse injuries such as medial tibial stress syndrome, patellofemoral pain, patellar tendinopathy, iliotibial band syndrome and plantar fasciitis.

In literature there is no consensus about the etiology of RRIs. An overuse type injury is caused by a disbalance between load and adaptation time. When a repetitive load is too high for a structure an injury can occur. Most RRIs are therefore the result of training errors, meaning training is too fast and too soon.

Known risk factors for RRIs are training volume, previous injuries and running to compete. Till now there is no evidence that risk factors such as age, gender, body mass index, running surface, running shoes and foot type play a major role in the etiology of an RRI.

It is important to get runners active without injuries and therefore good scientific evidence and data are necessary. This information is hard to find and often this information is not science based. This article will give an overview of what is known about the science concerning running and the prevention of RRIs.

Introduction

Running is a very popular sporting activity in the Netherlands. After the so called first running wave at the end of the seventies and the beginning of the eighties running became popular as a recreational activity. In the late nineties the second running wave started and till now the amount of runners increases every year. A major reason for this popularity is the number of recreational running events organized. Runners can prepare themselves for a running event and set a personal goal.[1]

In the Netherlands over 2.5 million people are running regularly. The majority are recreational runners in the age of 35 to 50 years. Male runners are outnumbering female runners but in coming years this difference will decrease dramatically looking at female runners starting to run and the organization of lots of ladies runs. Another important characteristic of the recreational runner is the setting of new goals. The recreational runner will try to run longer or more frequent thereby increasing the risk for obtaining an RRI.[1]

Running is a sporting activity that is easy to do and it can been done everywhere without difficult or expensive equipment. For running all someone needs is comfortable fitting clothing and a pair of running shoes and a body that can withstand running.[2] Running has an added value with respect to health and well being. Therefore it is essential to have knowledge of the running population and the potential for development of RRIs. When obtaining an RRI there is a chance that the runner will drop out and because of the disappointment this could lead to an inactive life style.[3]

It is often difficult to give a novice runner evidence based information with respect to running, training programs, running shoes and how to react in case of pain and RRIs. The recreational runner will search for information in the direct neighborhood and with other runners or will ask for information in running specialty stores and will search for information on the internet. When an RRI has occurred the runner will search for help an often consults a physiotherapist, general physician or sports physician. But most of the time it is difficult for the runner to find a reliable source for an optimal way to start running and get and stay active in running.

This article gives an overview of the current scientific knowledge on etiology and prevention of RRIs. Aspects of training, running surface, gender, BMI, foottype, running shoes, stretching en warming up and cooling down will be discussed.

Aspects of running

The biomechanical load of running is very high and this is often forgotten. When a person is landing during running the body in a few milliseconds has to absorb a shock of two to three times bodyweight.[4] A person of 70 kg who twice a week runs 10 kilometers has to absorb an extra load of 2,5 million kilograms.

Around 70 to 80% of recreational runners are heelstrikers.[5] The first phase in running is the heel strike. During this phase the foot makes contact with the running surface. The second phase is the stance phase. During this phase the foot has fully contact with the running surface and the impact shock will be active absorb by the foot. This shock absorption is partially done with pronation of the midfoot and therefore pronation of the foot is a physiological phenomenon. The last phase is toe off in which the foot is accelerating and is loosing contact with the running surface.

From a biomechanical point of view there is no big difference in external load between running on soft or hard running surfaces. The runner adapts to different running surfaces by changing the stiffness of the lower extremity.[6]

Barefoot or minimalistic running seems to become a hype. In 2010 Daniel Lieberman published a high profile article in Nature on barefoot running.[7] In this article Lieberman shows that a person who is running barefoot will avoid a heel strike and will adopt to a mid foot or forefoot landing pattern. From an evolutionary point of view our current foot is developed from barefoot walking and running.[8] Therefore it could be possible that our foot is not accustomed to land on the heel when running shod. With the introduction of running shoes with shock absorption this has lead to a different running pattern from midfoot to heelstrike caused by the use of running shoes.[9]

Running related injuries (RRIs)

According to research of consumer safety, running related injuries (RRIs) are runner up in Dutch injury statistics.[10] From these statistics it becomes clear most RRIs are caused by overuse en one third of the injured did obtain the same injury before. Of all RRIs 35% is treated medically or by a physiotherapist. From this group 75% is treated by a physiotherapist and 9% of the injured runners consult the general practitioner.[10]

An overuse injury can occur when the load of subsequent training sessions is too high and the recovery period is too short. Factors that play an important role are frequency, intensity and duration of the training.[4] Structures of the musculoskeletal system can adapt in a positive or negative way to training.[11]

Positive adaptation occurs when a load is followed by an appropriate time for recovery of the body. When different training stimuli are given over time and the balance between load and regeneration time is adequate the body adapts positively and the musculoskeletal will get stronger in resisting higher loads. On the other hand when the balance between load and the time for regeneration of the body is not optimal the body will adapt negatively resulting in overuse injuries.[4,11]

Most injuries in running are located in and around the knee. Lower leg and feet are also often involved. Most seen injuries are patellofemoral pain syndrome (PFPS), medial tibial stress syndrome (MTSS), patellar tendinopathy, plantar fasciitis and iliotibial tract syndrome.[12-20]

Incidence of running related injuries

The incidence of RRIs is normally expressed in injuries per 1000 hours of running. In this way different studies can be compared. The incidence of RRIs is between 2.5 and 59 injuries per 1000 hours of running.[1] Buist et al reported an incidence of RRIs of respectively of 30 and 38 injuries per 1000 hours of running in a group of novice runners preparing a 4 mile run with two different training schedules.[21]

These incidences are quite high when for example compared to injuries in soccer. In training and match there are respectively 5.0 and 24 injuries per 1000 hours of playing soccer.[22]

Often the injury incidence is expressed in injuries per 100 runners. In this incidence rate no information on exposure is available. Every year 19.4% to 79.3% of all runners at different levels of running obtain an RRI.[23]

The results of different studies on the incidence of RRIs are wide apart. Different aspects like definition of an RRI, the level of running and the duration of the follow up should be taken into account.

Etiology of running related injuries

There is much scientific information on running and running related injuries but till now there is little agreement and evidence on the etiology of RRIs.[17, 23] In general a few risk factors can be associated with RRIs but there is no information on specific RRIs and etiological risk factors. RRIs are often defined as a problem which causes the runner pain or disability. In large randomized trials there is no specific diagnosis but injuries are specified by location.

Risk factors that could be related to the etiology of RRIs can be divided in intrinsic or extrinsic factors. Another commonly used subdivision is to divide these factors into in three categories; training variables, anthropometrical and biomechanical factors.

Training variables

Most common training related risk factors in respect to RRIs are volume of running, stretching, warming up, cooling down, running surface and running shoes.[17, 23, 24]

Two studies showed that when running over 20 miles a week there seems to be a higher risk for obtaining an RRI.[17,23] Another often mentioned risk factor to prevent an RRI is stretching. This is often mentioned in literature but also in the running community. In literature no preventive effect of stretching has yet been found.[15, 23, 24]

A randomized controlled trial (GRONORUN 1) studied the effect of two training programs with different durations in the preparation for a 4 mile recreational running event on the incidence of RRIs in novice runners.[21] In this GRONORUN 1 study one group trained for 8 weeks and the other followed a more gradual program during 13 weeks. No differences on the incidence of RRIs between the two groups were found.[21] This study showed that participants who where active in sports with no axial loading (swimming, cycling) were at higher risk to develop an RRI.

Another risk factor that is often believed to be related to RRIs is running surface. Is it often said that running on a soft surface prevents RRIs but in literature there are no data to support this popular theory.[17,18,21] The reason for this is probably that humans adapt to the stiffness of the lower extremity to compensate for running on different surfaces.[6]

Running shoe manufacturers and running shops emphasize the value of good running shoes and their role in preventing RRIs. When someone is willing to take up running an advice by a specialist on good shoes in running shops is essential according to these running shops.

Running shoes are advocated for their effect on stability, motion control, as well as comfort and protection. These factors should lead to better running performance and would decrease the amount of RRIs. In a review on the effect of running shoes on performance and prevention of RRIs Richards et al. showed that there is no evidence for the mentioned characteristics of running shoes and their possible effect on performance and prevention of RRIs.[25]

Recently Knapik et al. published two large randomized clinical trials studying the effect of the combination foottype and running shoe and the effect on the incidence of RRIs.[26,27] Foottype was measured statically and divided in three different types; neutral foot, high arch and flat feet. The control group received a neutral cushioning shoe. The experimental group received a shoe according to foottype. The Runners World shoe advisor was used for the best running shoe for the neutral foot, high arch and flatfoot. Both studies with over 3000 participants did not show a preventive effect of a shoe advice on foottype and the prevention of RRIs.[26,27]

The most important risk factor that is often overlooked as a risk factor is the training for running.[4] According to Hreljac all RRIs are caused by training errors by running too often, too long or too (too much, too soon) intense and that the progression in running per week is too high.[4]

Anthropometrical variables

Different etiological variables mentioned by runners themselves are gender, age, body mass index (BMI) and their history of previous injuries. Men and women are quite the same as far as susceptibility for injuries is concerned.[12,15,20,23] Generally speaking, male runners get injured more often, while female runners develop stress fractures more frequently then male runners.

The influence of age in obtaining an RRI is still not clear. [12,15,20,23] On the one hand, one might assume that the aging process influences the structures of the musculoskeletal system in a negative way: they might be able to carry less load. On the other hand, the speed with which older people run, is often lower. Because of this, the pressure on the body will decrease. Another explanation could be that only people who are not or less susceptible to injuries keep running. In this way, a relatively healthy population of older runners remains. This phenomenon is sometimes called the "healthy runner effect".

An association between body mass index (BMI) and RRIs has been investigated more often but there seemed not to be a significant difference.[12,15,20,23]

People who have been injured in the past, are more likely to develop new injuries. [10] In both men and women an injury in the past is an important risk factor for obtaining a new RRI. [15,17,23]

Anatomical variables

Often, a runners foot type is related to injuries. For example, a pes cavus results in a stiffer foot that clearly influences the biomechanics of the lower leg. This foot is less able to absorb the shock, because of which the load on the lower extremity increases. This could lead to a greater risk of developing an RRI. With flat feet (pes planus) there are supposedly also bigger risks on RRIs. However, large prospective studies are missing and there is no clear correlation between foot type and obtaining RRIs. [26, 27, 28]

Other anatomical variables like varus and valgus of the knee, ROM of the hips and the ankles, also lack the causality for obtaining an injury. [28,29]

Biomechanical variables

Biomechanical factors that might be connected to RRIs are kinetic variables like the active force, impact force and loading rate. There does not seem to be a relation between kinetic variables like the impact force and other vertical ground reaction forces on the lower extremity and the origination of RRIs. [5]

Another often mentioned risk factor in the running community is the so called pronation of the foot. A novice runner visiting a special running store and getting a running analysis that shows a pronating running pattern, will most likely leave the shop with anti pronation or stability shoes. There is no evidence found to support this assumption. As said earlier, pronation is a physiological mechanism that absorbs forces during the landing and stance phase of the foot. Several surveys have shown no relation between a pronating running pattern and a higher risk of an RRI. [25]

Studies conducted by Knapik in which participants got running shoes based on the shoe advice of Runners World, no association was found between pronation of the foot and the occurrence of RRIs. [26, 27]

Opinion and concluding remarks

Running is a popular and healthy sport. It is easy to perform, easy accessible, relaxing and it gives a boost to social coherence. As stated in a Dutch report; ''More exercise with Start ot Run'', it appears that after 6 months, 70% of the novice runners are still running.[2] There seems to be a behavioral change that is so needed to get and to keep people active.

Unfortunately, injuries occur that may lead to ceasing all running or other sporting activities. Proved risk factors are running distance, history of injuries and competing in running. Gender, age, BMI foot type, running surface and type of shoes don't increase the chance of injuries. RRIs are multi factor injuries. But the most important cause of an RRI is overload; this is running too much, too fast, too soon.

The information that is available in the running community is often without scientific foundation and often originates from the running industry. This industry has an annual turnover of 15 billion dollars. For a novice runner it is hard to find his or her way in this jungle of information concerning running. For the physician and physical therapist it is not always easy to answer the questions of the runner competently and soundly.

Consumer Safety has created a starting point on the internet with practical and reliable information on running and injuries.[30] Theoretically, everybody can run, and should be stimulated to do so. Just buy any pair of running shoes and carefully start jogging. One should just be able to have a conversation without breathlessness. Should people not be active in sports and exercise for a long time, they should start with walking for 30 to 60 minutes twice a week for a period of 4 to 6 weeks.

People can start jogging twice a week. Every training should consist of jogging 10 times 1 minute and active resting in between. After this, the exercise can be increased with 10% per week when no (little) pain or injuries have occurred. In case of (little) pain during or after a running exercise, then no increase of exercise is allowed in the next week. The runner must learn to listen to his or her body instead of focusing on the running schedule. If (little) pain persist for more than a few hours, the runner should be alert and take it easy during the next running exercise. If a runner has a chronic complaint or problem, he can be referred to a sports physical therapist or sports physician.

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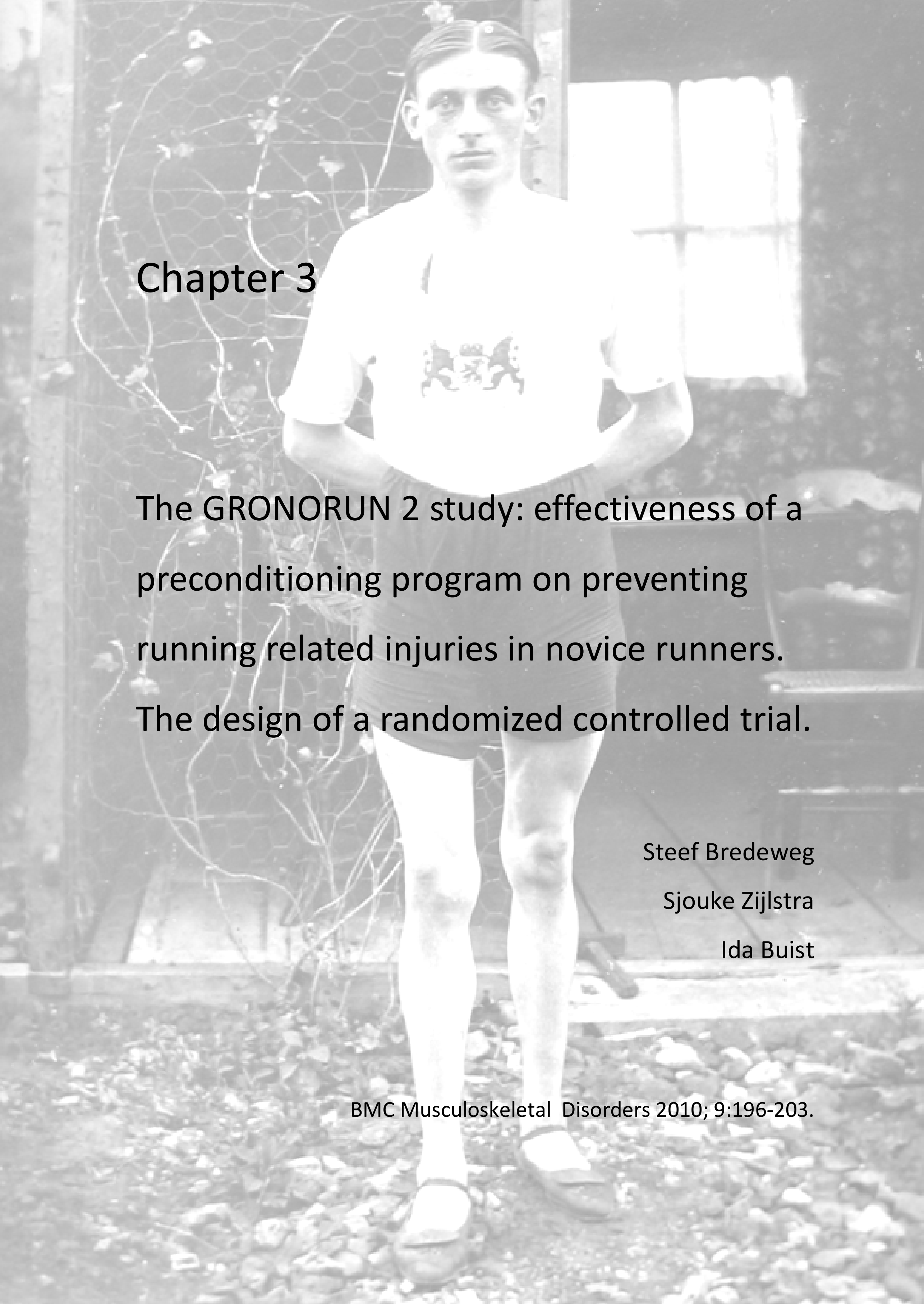

Chapter 3

The GRONORUN 2 study: effectiveness of a preconditioning program on preventing running related injuries in novice runners. The design of a randomized controlled trial.

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Abstract

Background

Distance running is a popular recreational exercise. It is a beneficial activity for health and well being. However, running may also cause injuries, especially of the lower extremities. In literature there is no agreement what intrinsic and extrinsic factors cause running related injuries (RRIs). In theory, most RRIs are elicited by training errors, this too much, too soon. In a preconditioning program runners can adapt more gradually to the high mechanical loads of running and will be less susceptible to RRIs. In this study the effectiveness of a 4-week preconditioning program on the incidence of RRIs in novice runners prior to a training program will be studied.

Methods/Design

The GRONORUN 2 (Groningen Novice Running) study is a two arm randomized controlled trial studying the effect of a 4-week preconditioning (PRECON) program in a group of novice runners. All participants wanted to train for the recreational Groningen 4-Mile running event. The PRECON group started a 4-week preconditioning program with walking and hopping exercises 4 weeks before the start of the training program. The control (CON) and PRECON group started a frequently used 9-week training program in preparation for the Groningen 4-Mile running event.

During the follow up period participants registered their running exposure, other sporting activities and running related injuries in an Internet based running log. The primary outcome measure was the number of RRIs. RRI was defined as a musculoskeletal ailment or complaint of the lower extremities or back causing a restriction on running for at least three training sessions.

Discussion

The GRONORUN 2 study will add important information to the existing running science. The concept of preconditioning is easy to implement in existing training programs and will hopefully prevent RRIs especially in novice runners.

Background

Running is a popular activity and can be practised everywhere. The health benefits are substantial but runners get injured regularly. The incidence of running related injuries (RRIs) is high. Various studies in different populations reported rates of RRIs ranging from 19-79%.[1-9] RRIs are often located in the lower extremities with knee and lower leg mostly affected.[3,6,7,10-12] There is no agreement on the cause of RRIs. In the current literature, possible intrinsic and extrinsic risk factors are identified, but there is still no exact cause for an RRI. Van Mechelen[13] and van Gent et al[9] proposed risk factors that have been significantly related to RRI; excessive weekly running distance, previous injury, lack of running experience and competitive running.

Clinical studies showed that over 60% of RRIs could be attributed to training errors.[14] Hreljac[14] stated that all overuse running injuries are the result of training errors. From this point of view a RRI is a disturbance between the external load applied to the body and the injury threshold of a biological structure of the body. In this dose-response relationship there are four components applicable to the novice runner.[14] The first component is the current status of the musculoskeletal system of the novice runner. The second component is the type of applied stress (i.e. running). Thirdly, the frequency, intensity and duration of the applied stress (i.e. running) and finally, the adaptation and recovery times between running sessions are major determinants of this dose relationship.

Under normal circumstances the musculoskeletal system adapts to the level of stress placed upon it.[14-16] When an optimal level of stress is applied to the musculoskeletal system, along with an adequate recovery time, the musculoskeletal system will increase in strength. On the other hand, when the applied stress is too high or the recovery time is too short the tissue of the musculoskeletal system will be weakened and the likelihood of sustaining a subsequent overuse injury is high.[14,16,17] Mechanical load (i.e. running) applied to the human body can cause a physiological or pathological adaptation to this mechanical loading, resulting in respectively a training effect or overuse injury.[17]

The musculoskeletal system of the novice runner is normally not adapted to the repetitive and relatively high impact forces of running because novice runners are frequently physically inactive before they start to run.[10,18] In most regular running programs for novice runners the biomechanical load is high from the start of the program in terms of frequency, intensity and duration.

The first GRONORUN study showed that previous sports participation without axial loading was an important predictor for RRIs in novice runners.[7,19] From this knowledge a strategy can be chosen to strengthen the lower extremities to achieve a positive physiological adaptation of the musculoskeletal system before starting a training program for novice runners. The applied external load of this so called preconditioning program will stress the lower extremities and as a result the lower extremities will positively adapt to the applied stress. In this way there is a stepwise transition of biomechanical load which makes it easier for the musculoskeletal system of the lower extremities to withstand the demands of running. Other studies in athletes and military populations showed a positive effect of a preconditioning program on the incidence of sports and overuse injuries in different populations.[20-23]

In a preconditioning program for running, the program needs to load the musculoskeletal system in a sport-specific way. Therefore, in this randomized controlled trial a preconditioning program with walking and hopping prior to the training program for novice runners will be studied. We hypothesize that the novice runner can adapt more gradually to the external impact forces of running with a preconditioning program prior to the training program and will be less susceptible to RRIs.

Methods/design

The GROningen NOvice RUNing 2 (GRONORUN 2) study is a randomized controlled trial with a 13-week follow-up. Participants were randomized into two groups: an active control (CON) group and an intervention (PRECON) group. The PRECON group will receive a 4-week preconditioning program prior to the start of the training program. Recruitment of participants for the GRONORUN 2 study took place in the period April – June 2008 and data collection started in July 2008. The study design, procedures and informed consent procedure were approved by the Medical Ethics Committee of the University Medical Center Groningen (No. 2007.217). All participants provided written informed consent. Guidelines were followed according to the Consort Statement.[24]

Study population

In the period April – June 2008, participants who were willing to start a "beginners 9-week program'' in preparation for the Groningen 4-Mile running event were recruited with advertisements in local media in the northern part of the Netherlands. For this study participants were not obliged to participate in the Groningen 4-Mile running event. The Groningen 4-Mile running event is a popular annual recreational running event that takes place in October. After initial registration, potential participants were sent written information about the study along with a baseline questionnaire and invitation for an initial interview in the Center for Sports Medicine at the University Medical Center Groningen (UMCG), The Netherlands.

Inclusion & exclusion criteria

Healthy subjects between 18 and 65 years of age who had no injury of lower extremities or lower back in the last three months prior to inclusion, who had not been running on a regular basis in the previous twelve months who were willing to start a beginners program were eligible for inclusion in the study. Potential participants were excluded to the study if there were absolute contraindications for vigorous physical activities according to the American College of Sports Medicine[25] or in case of unwillingness to keep a running log.

Sample size

A power calculation was carried out for the main outcome variable, i.e. running related injury (RRI), using a logistic rank survival power analysis. As stated before, the incidence of RRIs varies between 19-79%.

A reduction of 25% on the incidence of RRIs in the PRECON group is considered clinically significant and relevant. The expected incidence of RRIs is 40%.[4,10] With a hypothesized 25% reduction of RRIs in the PRECON group compared to the control group, a total of 360 runners (2x180) is needed for a power of 80% and an alpha of 0.05. Assuming an attrition of 15% in the intervention period and follow up period, a total of 414 (2x207) novice runners are needed to detect an effect of the PRECON intervention.

Baseline questionnaires

All participants filled in an online questionnaire before baseline measurements were taken. In case potential participants had no access to the internet a questionnaire was sent by mail. Demographic and anthropometric variables that were collected were age, gender, body weight and length. Conditions related to risk factors for cardiovascular diseases were assessed using a series of questions according to the American College of Sports Medicine.[25] Past musculoskeletal complaints of the lower extremities and back were assessed by questions on the anatomical site and the number of days lost to work and/or sporting activities. When a musculoskeletal complaint was caused by a sporting activity it was registered as a previous sports injury. When the musculoskeletal complaint was caused by running in the past it was registered as a previous running injury. Sports participation was measured by asking whether someone was participating in sports in the past twelve months (yes/no), type of sport and mean hours of sport participation per sport a week. Furthermore a question on running experience in the past (“did you ever structurally run before”) was added to assess the novelty to running.

After receiving the complete questionnaire potential participants were invited for an initial interview by an experienced sports physician at the Sports medicine center of the University Medical Center Groningen. The purpose of the initial interview was to screen for cardiovascular diseases and abnormalities of lower limb and to ensure that the participants were eligible and were adequately informed about the study before signing informed consent for the GRONORUN 2 study.

Baseline orthopaedic measurements

Hip function was measured by using a universal goniometer with arm length 30 cm from axis to tip. The internal and external range of motion of the hip was assessed with the participant supine and the tested hip and knee flexed to 90°. Knee flexion and extension ranges of motion were assessed with the participant in supine position. The goniometer was placed on the lateral aspect of the knee, with the axis of the goniometer in line with the greater trochanter and the lateral malleolus. Ankle plantar flexion and dorsi flexion were measured both with the knee fully extended and flexed to 90°. One arm of the goniometer was aligned with the fibular bone and the other with the plantar surface of the foot. Furthermore, the navicular drop was assessed by measuring the change in the height of the navicular tuberosity between a participant sitting with the subtalar joint in neutral position and standing, weight bearing with the subtalar joint in relaxed stance, as described by Brody.[26] The navicular drop is a valid method to indicate the amount of foot pronation.[27] Intratester and intertester reliability of this technique is ranging from .73 to .96.[28] Measurements were made twice for each foot, with results being averaged. These measurements were identical to the GRONORUN 1 study.[19]

Randomization

After baseline measurements and informed consent, participants were randomly assigned to the CON or the PRECON training program.

To ensure that both groups were equal in terms of injury risk, a stratified randomization was performed based on three variables; current sporting activities, previous injuries and gender. Based on current sporting activities, there were three categories of novice runners. The first category consisted of novice runners who already were participating in a sport in which axial load i.e. running, walking or jumping, was integrated. The second category was formed by novice runners who already were participating in sporting activities without axial load, like swimming and cycling. The third and last category was formed by novice runners who did not participate in any sporting activities at baseline measurements.
In a study by Macera,[1] a 74% increased risk was found in runners with a positive history of previous injuries. In this study, previous musculoskeletal complaints with an impact of activities of daily life, work or sporting activities were defined as a previous injury. Since it is not clear whether the high rate of re-injury is caused by incomplete healing of a previous injury or a biomechanical problem, a differentiation in time is made. A distinction can be made between no previous injury, injuries sustained in the last 12 months before baseline measurements and injuries sustained more than 12 months before baseline measurements. The participants were also stratified for gender because men and women differ in incidence of RRIs and localisation of these injuries.[6,9] In total eighteen strata were formed by gender, previous injury (no injuries, injury 3 till 12 months ago and injuries longer then 12 months ago) and sporting activities (no, with axial load and without axial load). From each stratum, participants were randomly allocated to intervention or control group by drawing a sealed opaque envelope. Each stratum box contained equal numbers of control and intervention envelopes.

Participant flow

The study design and participants flow are shown in Additional file 1. A total of 500 people were interested to participate in the GRONORUN 2 study and responded to the call for novice runners. To all of those who reacted on the advertisements, an information brochure in which the study protocol was clearly described, a baseline questionnaire and an appointment at the UMCG was given. Forty four did not confirm their appointment for the initial interview nor filled in the baseline questionnaire. Of those who confirmed the appointment for the initial interview and filled in the questionnaire (n=456), four failed to attend the initial interview. Eventually, of the 452 persons who visited the UMCG for an initial interview, 20 were excluded. Reasons for exclusion were: already participating in running (n=11), musculoskeletal injury of lower extremities or back at baseline (n=6) and contraindications for vigorous physical activity (n=3). After baseline measurements and stratification, 432 participants were randomly assigned to the intervention group (n=211) and to the control group (n=221).

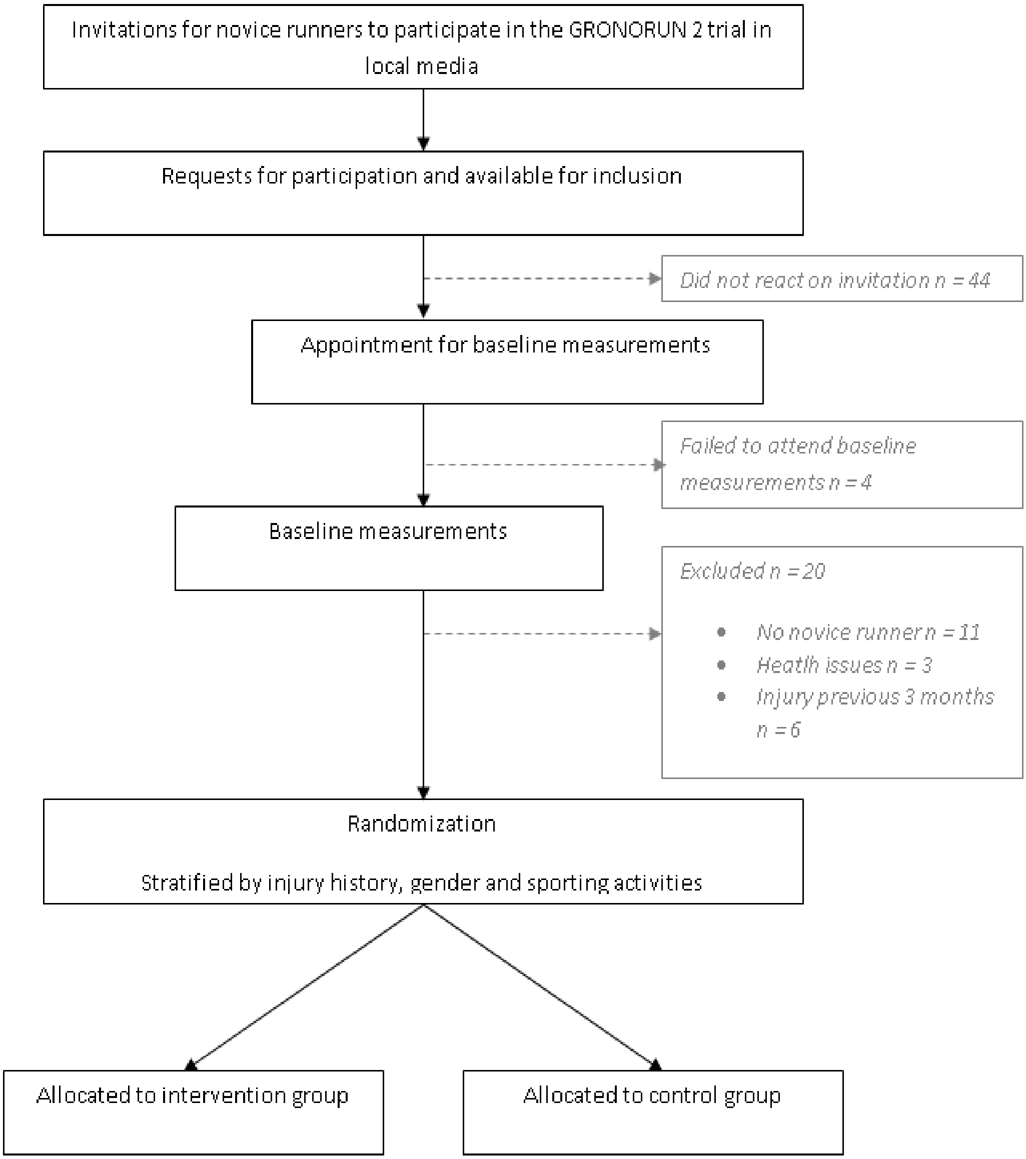


Figure 1: Flow chart of the GRONORUN 2 study

Training program

4 –week preconditioning program

The PRECON group received a 4-week individual preconditioning training program (Table 1). This program gradually increases biomechanical load on the lower extremities with walking and hopping sessions. Participants were instructed to walk briskly on their running shoes three times a week. During two of the three walking sessions per week, participants carried out hopping exercises. After every five minutes of walking a session of hopping was carried out. In approximately half an hour six sessions of hopping were carried out. The number of hops as well as the weekly walking distance increased gradually. The PRECON group received verbal information about the correct hopping technique at the initial interview and there was a video instruction on the personalized environment of the internet based training log of the PRECON group.

Table 1: The 4-week preconditioning (PRECON) program with walking and hopping

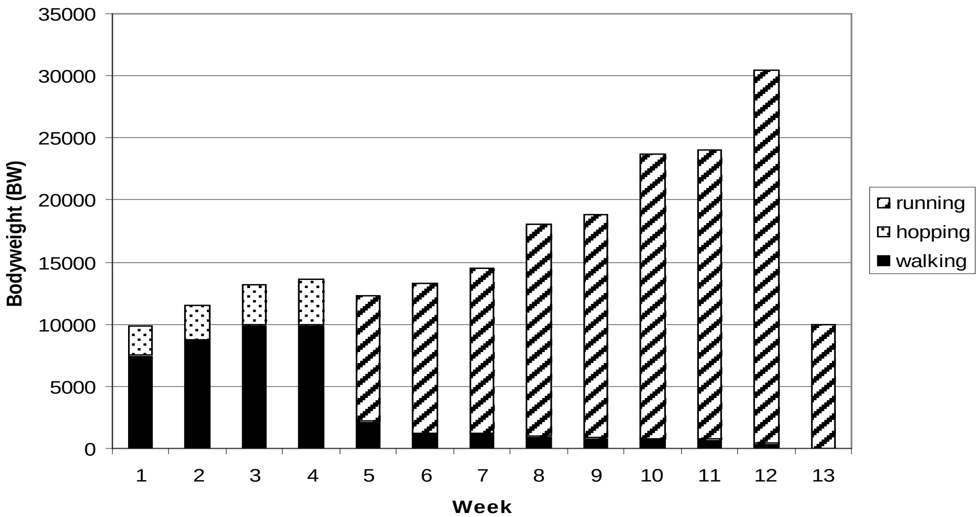
	PRECON training 1			**PRECON training 2**			**PRECON training 3**	**Total**	
	Walk (min)	Hop	*(rep.)*	Walk (min)	Hop	*(rep.)*	Walk (min)	**Walk (min)**	**Hop**
week 1	5	50	*(6)*	5	60	*(6)*	30	**90 [7500 BW]**	**660 [2310 BW]**
week 2	5	60	*(6)*	5	70	*(6)*	45	**105 [8750 BW]**	**780 [2730 BW]**
week 3	5	70	*(6)*	5	80	*(6)*	60	**120 [10000 BW]**	**900 [3150 BW]**
week 4	5	80	*(6)*	5	90	*(6)*	60	**120 [10000 BW]**	**1020 [3570 BW]**
week 5	Start of the 9-week training program								

The content of the PRECON training program is expressed in minutes of walking (Walk) and the number of hopping in place (Hop) and the amount of repetitions (rep.) of walking and hopping. The right column contains total minutes of walking and total performed hops each week. In the last two columns the additional load of walking and hopping each week is expressed between brackets [ ] in bodyweight (BW)

The correct technique of hopping in place was a relaxed standing position with a distance of approximately 30 cm between the left and right foot with both hands in the sides. Then small jumps in place were performed with the forefeet almost keeping contact with the ground. During the 4 weeks of the preconditioning program of the PRECON group the CON group was instructed to do their normal exercise routine and sporting activities if applicable.

In the first training week, in which both groups are starting to run, the theoretical extra biomechanical load of running (10 km/h; total 30 min, impact 2.0 bodyweight (BW) per landing) and walking (5km/h, total 30 min, impact 1.0 BW per landing) is approximately 12,500 extra BW. Walking is a low cyclic impact force activity and hopping is a high cyclic impact force activity. Both activities stress the body in a cyclic way, especially the lower extremities, so that the body has to positively adapt to the biomechanical stimuli. In the first week of the PRECON program the extra biomechanical load of walking (5km/h, total 90 min, impact 1.0 BW per landing) and hopping (660 hops, impact per hop 3.5 BW per landing) was approximately 9810 extra BW. In week 2 there is 11480 extra BW, in week 3 13150 BW and in week 4 13570 BW (Figure 2).

Figure 2: Biomechanical load for the PRECON (week 1-13) and the CON (week 5-13) group.



The 9-week training program

Nine weeks before the Groningen 4-Mile running event all participants were instructed to start their 9-week training program (Table 2). Participants of the CON and PRECON group received the same general written and oral information on intensity of running and on warming up and cooling down. Participants were instructed to walk briskly for 5 minutes as a warm up, and 5 minutes as cool down. Given that the best available evidence indicates that stretching before or after exercise does not prevent muscle soreness or injury [29], participants were instructed not to perform stretching exercises before, during or after the training sessions.

The frequency of running was equal in both groups. Each training week except the last week i.e. the week of the Groningen 4-Mile running event, consisted of three training sessions represented by a combination of running and walking. Participants were encouraged to run on Monday, Wednesday and Saturday or on Tuesday, Thursday and Sunday. Runners were advised to run at a comfortable pace at which they could converse without breathlessness. Both groups trained individually, without a trainer on a self-chosen course.

Table 2: The 9-week training program for both groups

	Training 1			**Training 2**			**Training 3**			**Total**	
	run	*walk*	(rep.)	**run**	*walk*	(rep.)	**run**	*walk*	(rep.)	**run**	*walk*
week 1	**1**	*1*	(10)	**1**	*1*	(10)	**1**	*1*	(10)	**30**	*27*
week 2	**2**	*1*	(6)	**2**	*1*	(6)	**2**	1	(6)	**36**	*15*
week 3	**4**	*2*	(3)	**4**	*2*	(4)	**4**	*2*	(3)	**40**	*14*
week 4	**6**	*2*	(3)	**5**	*2*	(3)	**6**	*2*	(3)	**51**	*12*
week 5	**6**	*2*	(3)	**9**	*2*	(2)	**6**	*2*	(3)	**54**	*10*
week 6	**8**	*2*	(3)	**15**	*0*	(1)	**15**	*5*	(2)	**69**	*9*
week 7	**10**	*2*	(2)	**15**	*5*	(2)	**10**	*2*	(2)	**70**	*9*
week 8	**30**	*0*	(1)	**15**	*5*	(2)	**30**	*0*	(1)	**90**	*5*
week 9	**30**	*0*	(1)				**The Groningen running 4-Mile event**			**30**	*0*

The content of each training session is expressed in minutes of running (run), minutes of walking between the running sessions (walk) and number of repetitions (rep.). The last two columns contains the total minutes of running and walking for each week.

Outcome measures

The primary outcome of the GRONORUN trial was the number of RRIs in both groups. A runner could only have one RRI. Definition of a RRI in this trial was; running related musculoskeletal ailment of the lower extremities or back, causing a restriction of running for at least one week, i.e. three consecutive training sessions.

Information on RRIs and exposure data was collected using an internet based running log. Each of the participants received a study number and a password to enter a personal environment of the web based training log. After each training week participants had to fill in their running activities, other sport activities and injuries.

Per training session the total minutes of running, total minutes of walking and injuries were registered. Data on injuries were collected by registering anatomical site of the body and severity of pain. Severity of pain was subdivided in pain without limitation (no RRI), pain that caused a restriction of running (scored as an RRI) and pain which made running impossible RRI (scored as an RRI). In case of skipping a training session, the reason (RRI, other injury, motivation, illness or remaining reason) for it was asked. When a “running related injury” was the reason for not training, information on anatomical site and severity was asked. To point out the anatomical site of an injury, a picture of the lower body was shown after reporting a RRI. By clicking on the anatomical site of the RRI, the same spot was appointed in red. When participants did not enter their digital training log after one week, a reminder was send by email automatically. In case of not having access to the Internet, all participants had also a hard copy of the running log.

Statistical analyses

To evaluate the success of the randomization, baseline characteristics of participants in the CON and PRECON group were compared using 2-tailed t-tests for normally distributed continuous variables. The χ^2 statistic was used for discrete variables. To evaluate the effect of the PRECON program on the number of injured runners in both groups, a χ^2-test was used. The log-rank test is used to compare the Kaplan-Meier curves of the injured runners of the PRECON group and the CON group, analyzing the difference between these two groups in the probability of an RRI at any point in time. All analyses were performed following the “intention to treat” principle. Differences were considered statistically significant at $P < .05$. All analyses were performed using SPSS version 16.0 (SPSS Inc, Chicago, Ill).

Discussion

To study the population of novice runners it is important because the main reason for discontinuation (drop out) of a running program is injury.[18] Negative experiences, caused by an injury that occurs while training for a running event, have the potential to significantly affect the future physical activity of each individual. It is also known that (fear of) sustaining an injury is associated with failure to start and maintain a physically active lifestyle.[30]

As stated by Yeung[31] there is a need for more well controlled trials to shed light on possible interventions for the prevention of lower limb injuries in runners. Current studies on the effect of interventions for preventing running injuries in recreational runners are scarce. The GRONORUN 1 study showed no effect of a more gradual training program in the novice recreational runners.[7]

In preventive medicine it is important to develop interventions based on the understanding of the etiology and mechanisms of injury and the preventive intervention has to be acceptable, practical and adopted by athletes and sport bodies so that the implementation of the intervention can be successful.[32] The proposed intervention in this RCT is practical, easy to do and therefore has a good chance for success in terms of compliance, efficacy and effectiveness.

Results of this GRONORUN 2 study can be implemented in the existing training program for novice runners and the new preconditioning training program can be implemented on a regional, national and international level. In this way, a more scientific based training program for novice runners can be developed and novice runners will feel safer in starting a running program.

With this study there is also a unique opportunity to start more clinical and preventive studies on overuse running related injuries. The newly gathered information will be transferred into new clinical and preventive studies in the future.

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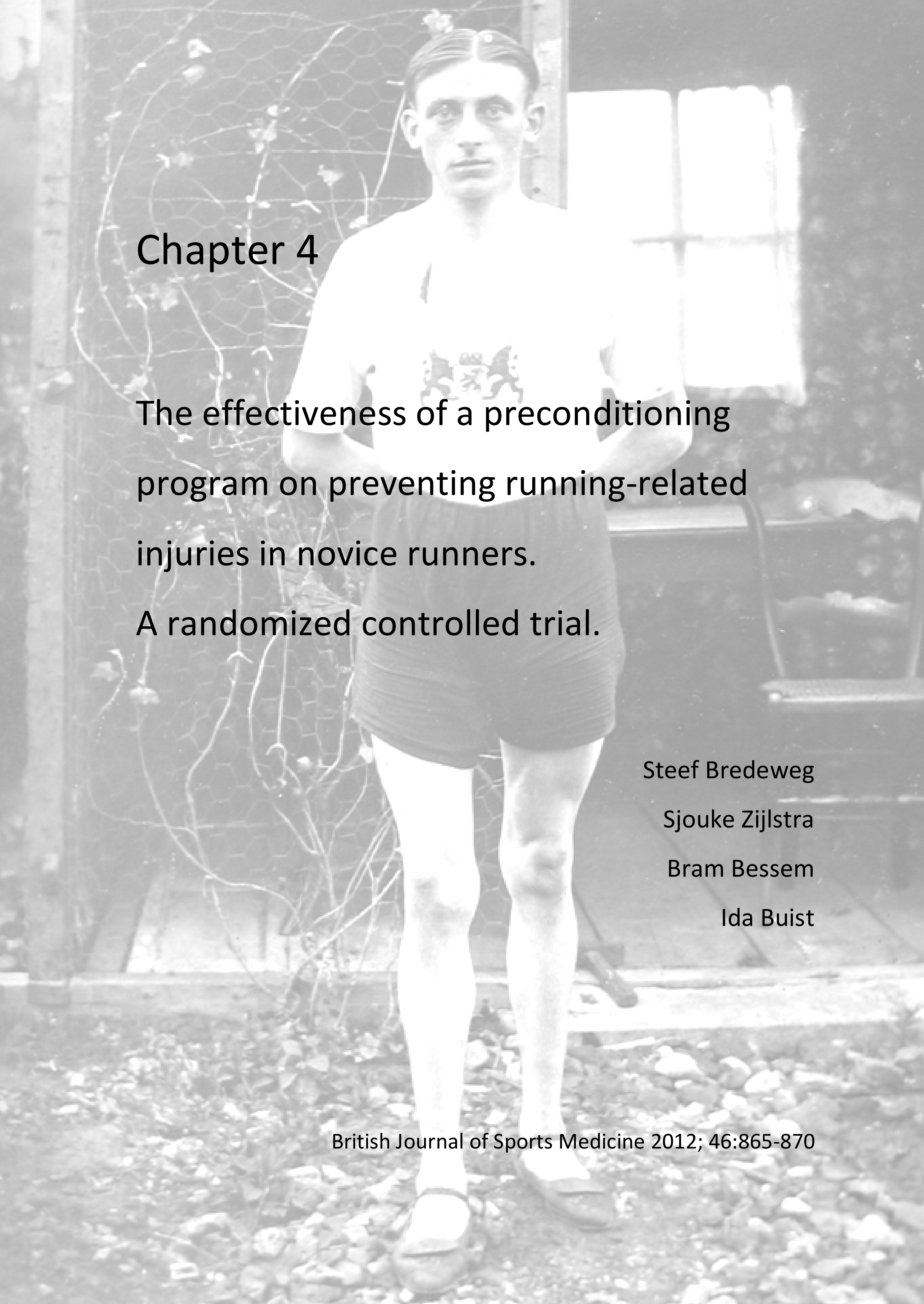

Chapter 4

The effectiveness of a preconditioning program on preventing running-related injuries in novice runners. A randomized controlled trial.

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Abstract

Background: There is no consensus on the aetiology and prevention of running-r injuries in runners. Preconditioning studies among different athlete populations show positive effects on the incidence of sports injuries.

Hypothesis: A four week preconditioning program in novice runners will reduce the incidence of running-related injuries.

Study design: Randomized controlled clinical trial; Level of evidence, 1.

Methods: Novice runners (N = 432) prepared for a four mile recreational running event. Participants were allocated to the 4-week preconditioning (PRECON) group (N = 211) or the control group (N = 221) The PRECON group started a four week training program, prior to the running program, with walking and hopping exercises. After the four week period both groups started a nine week running program. In both groups information was registered on running exposure and running-related injuries (RRIs) using an internet-based running log. Primary outcome measure was RRIs per 100 runners. An RRI was defined as any musculoskeletal complaint of the lower extremity or lower back causing restriction of running for at least a week.

Results: The incidence of RRIs was 15.2% in the PRECON group and 16.8% in the control group. The difference in RRIs between both groups was not significant (X^2 = 0.161, df = 1, P = .69).

Conclusion: This prospective study demonstrated that a four week preconditioning program with walking and hopping exercises had no influence on the incidence of RRIs in novice runners.

Introduction

Recreational and competitive running is very popular worldwide and the number of runners is ever-increasing. Running is an easy sports activity to maintain an active healthy lifestyle, and has beneficial effects on cardiorespiratory fitness, weight control and mental health.[1] Sooner or later however, many novice, recreational or competitive runners sustain injuries. The incidence of running-related injuries (RRIs) is high. Incidence rates vary from 20.3% to 84.9% and from 3 to 59 RRIs per 1000 hours of running.[2-6] Most RRIs are overuse musculoskeletal injuries of the lower extremity.[3,4,7-11] The aetiology of RRIs is multifactorial and diverse. Various purported intrinsic and extrinsic risk factors for RRIs have been studied, but most studies on these factors show inconsistent or conflicting results.[11,12] There is evidence that a greater weekly training distance, history of previous injuries, lack of running experience, and running to compete are risk factors for lower extremity running injuries.[12,13] Hreljac states that many, if not all, running injuries are caused by training errors.[14]

Van Mechelen's opinion that the prevention of RRIs is primarily based on trial and error is still valid.[15] So far, little high-quality research has been done on the prevention of RRIs in novice or recreational runners.[4] Studies on the effects of interventions to prevent RRIs have methodological shortcomings, hence the continued need for controlled trials to shed light on such interventions.[16]

Buist et al showed that previous sports participation without axial loading (i.e. swimming, cycling) was an important predictor for RRIs in novice runners in contrast with sports with axial loading (i.e. soccer, hockey, basketball, volleyball).[17] From this observation it can be hypothesized that a lack of previous participation in sporting activities without axial loads is a risk factor for sustaining an RRI. Milgrom found that the type of physical activity of recruits prior to military induction was a major determinant for stress fracture risk in basic training.[18]

In a healthy situation the musculoskeletal system can adapt to mechanical loading and physical activity.[19,20] These mechanotransduction mechanisms converts mechanical forces into biochemical events in musculoskeletal tissue in a loading magnitude dependent manner.[19,20] When an optimal level of load is applied to the musculoskeletal system, its strength will increase given adequate recovery time. When loading is too high or the recovery time is too short however, the musculoskeletal system will be weakened and the likelihood of sustaining an overuse injury is increased.[14,19,20]

Novice runners are frequently inactive before they start running,[3,17,21] therefore their musculoskeletal systems are not used to the repetitive and high-impact forces of running.[14] In most running programs the biomechanical load is high from the start. When the musculoskeletal system of the novice runner cannot cope with this high load an RRI will occur.[14] The GRONORUN 2 study was designed based upon this knowledge.

The GRONORUN 2 study tests the effect of a preconditioning program on RRIs in novice runners. In a preconditioning program the body is being prepared for regular high-intensity training by exposing it to a sport-specific load that will gradually increase in time. Athletes often participate in a preconditioning program before a competitive season or a regular training period. A small number of studies among athletic and military populations positive effects of preconditioning programs in preventing sport-specific injuries.[22-28] No study has yet investigated the link between preconditioning programs and RRIs in novice runners.

In the present randomized controlled trial a preconditioning program was introduced in which novice runners prepared their body gradually for a high running load by doing walking and hopping exercises. The aim of the GRONORUN 2 study was to determine the effect of this preconditioning program on the incidence of RRI among novice runners. It was hypothesized that the lower extremity would positively adapt to the applied load and therefore the number of RRIs should decrease in the group receiving the preconditioning program.

Methods

Design

The GRONORUN 2 study is a two-arm randomized controlled trial with a 4-week preconditioning program and a nine week running program. The GRONORUN 2 study was registered under NTR1906, in the Netherlands Trail Register (NTR). The NTR is part of the WHO Primary Registries. The design of the study is described more extensively elsewhere.[29] The study design was approved by the Medical Ethics Committee of University Medical Center Groningen, The Netherlands under number (No. 2007.217). Guidelines according to the Consort Statement were followed.[30]

Participants, randomization and baseline measurements

Healthy participants willing to prepare a recreational four mile run with a beginners nine week training program, were recruited with advertisements in the local media in the Northern part of the Netherlands. Participants aged between 18 and 65 who had not sustained an injury of the lower extremity in the last three months before inclusion and who had not been running on a regular basis in the previous 12 months were eligible for inclusion in the study. Participants were excluded when absolute contraindications for vigorous physical activities were present according to the American College of Sports Medicine.[31]

After baseline measurements and informed consent, participants were randomly assigned drawing an opaque envelope to the PRECON group or the control group. To ensure that both training groups were equal in terms of a priori injury risk, a stratified randomization was performed. Participants were stratified for current sporting activities (no sport or axial or no axial sport), previous injuries (yes or no) and gender (male or female).

Participants had to fill in an internet-based baseline questionnaire.[29] All participants were seen by an experienced sports physician to screen for cardiovascular disease and abnormalities of the lower limb, to ensure that the participants were eligible for the GRONORUN 2 study.[29]

Preconditioning program (4 weeks)

Participants in the preconditioning (PRECON) group took part in a four week individual preconditioning program (Table 1). More information on PRECON program can be found elsewhere.[29]

Table 1: Four week preconditioning (PRECON) training program

	PRECON training 1			**PRECON training 2**			**PRECON training 3**
	Walk min)	Hop	*(rep.)*	Walk (min)	Hop	(rep.)	Walk (min)
week 1	5	50	*(6)*	5	60	(6)	30
week 2	5	60	*(6)*	5	70	(6)	45
week 3	5	70	*(6)*	5	80	(6)	60
week 4	5	80	*(6)*	5	90	(6)	60
week 5	Start of the nine week running program						
The content of the training session is expressed in minutes of walking (Walk), the number of hops in place (Hop), and the number of repetitions (rep.) of walking and hopping.							

Nine-week running program and running log

Directly after the four week PRECON program, the nine week running program started in which all subjects participated (Table 2). Information on RRIs and exposure data was collected using an internet-based running log. Detailed information on the running program and running log can be found elsewhere.[29]

Table 2 Nine week running program in minutes per week for the preconditioning group and the control group

	Training 1			Training 2			Training 3			Total	
	Run	Walk	*(rep.)*	**Run**	Walk	*(rep.)*	**Run**	Walk	*(rep.)*	**Run**	Walk
week 1	**1**	1	*(10)*	**1**	1	*(10)*	**1**	1	*(10)*	**30**	27
week 2	**2**	1	*(6)*	**2**	1	*(6)*	**2**	1	*(6)*	**36**	15
week 3	**4**	2	*(3)*	**4**	2	*(4)*	**4**	2	*(3)*	**40**	14
week 4	**6**	2	*(3)*	**5**	2	*(3)*	**6**	2	*(3)*	**51**	12
week 5	**6**	2	*(3)*	**9**	2	*(2)*	**6**	2	*(3)*	**54**	10
week 6	**8**	2	*(3)*	**15**	0	*(1)*	**15**	5	*(2)*	**69**	9
week 7	**10**	2	*(2)*	**15**	5	*(2)*	**10**	2	*(2)*	**70**	9
week 8	**30**	0	*(1)*	**15**	5	*(2)*	**30**	0	*(1)*	**90**	5
week 9	**30**	0	*(1)*	**20**	0	*(1)*	**Sunday 4-Mile**			**50**	0

The content of each training session is expressed in minutes of running (Run), minutes of walking between the running sessions (Walk) and number of repetitions (rep.).

Outcome Measure

The primary outcome measure of the GRONORUN 2 trial was RRIs per 100 runners. An RRI was defined as any musculoskeletal complaint of the lower extremity or back causing a running restriction for at least one week. Exposure time was defined as the time (in minutes) a subject had been running in the nine week program. Time spent on walking and hopping was not calculated as exposure time.

Power analysis and statistics

Sample size was calculated for the main outcome variable, i.e. running-related injury (RRI), using a logistic rank survival power analysis. As stated before, the incidence of RRIs varies between 20.3 and 84.9. A reduction of 25% on the incidence of RRIs in the PRECON group is considered clinically significant and relevant. The expected incidence of RRIs is 40%. With a hypothesized 25% reduction of RRIs in the PRECON group compared to the control group, a total of 360 runners (2x180) were needed for a power of 80% and an alpha of 0.05. Assuming an attrition rate of 15% in the preconditioning period and follow up-period, a total of 414 (2x207) novice runners are needed to detect an effect of the 4-week PRECON program.

Self assessed baseline characteristics from participants with exposure in the nine week running program were compared between groups using 2-tailed t-tests for normally distributed continuous variables. Chi-square tests were used for discrete variables. To evaluate the effect of the PRECON program on RRI, a Chi-square test was used. The log-rank test was used to compare the Kaplan-Meier curves of the subjects with an RRI in the PRECON group and the control group, analysing the difference between the training groups in the probability of an RRI at any time point. All analyses were performed following the "intention to treat" principle. Differences were considered statistically significant at $p<0.05$. All analyses were performed using SPSS version 18.0 (SPSS Inc, Chicago).

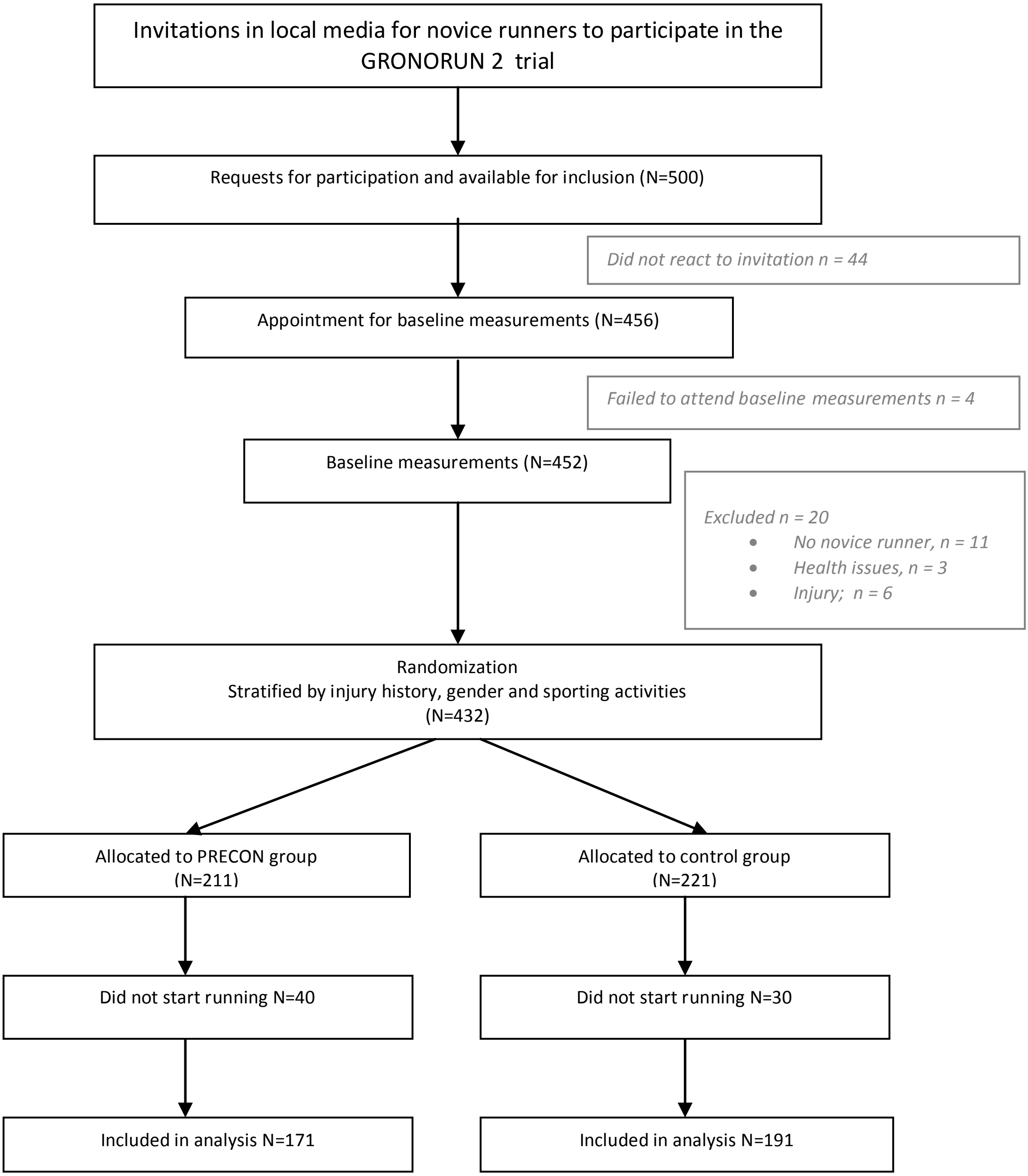

FIGURE 1 - Flow of participants through each stage of the GRONORUN 2 trial.

Results

Randomization and baseline characteristics

Figure 1 shows the flow of participants through the stages of the GRONORUN 2 study. Four hundred and thirty two novice runners were randomly assigned to the PRECON group (n = 211) or the control group (n = 221). Baseline characteristics of all participants can be found in Table 3.

Table 3 Baseline characteristics of participants in the preconditioning and the control group

Characteristics		**PRECON**	**Control**	**Total**
N		211	221	432
Women		138 (65.4%)	145 (65.6%)	283 (65.5%)
Men		73 (34.6%)	76 (34.4%)	149 (34.5%)
Age (yrs)		39.0 (10.7)	37.2 (10.9)	38.1 (10.8)
Weight (kg)		75.6 (15.0)	74.6 (14.3)	75.1 (14.6)
Body Mass Index (kg/m^2)		24.3 (3.9)	23.9 (3.3)	24.1 (3.6)
Running experience	No	105 (49.8)	103 (46.6)	208 (48.1)
	Yes	106 (50.2)	118 (53.4)	224 (51.9)
Previous injury	No	161 (76.3)	162 (73.3)	323 (74.8)
	>3, ≤12 months ago	7 (3.3)	11 (5.0)	18 (4.2)
	>12 months ago	43 (20.4)	48 (21.7)	91 (21.0)
Sporting activities	No	104 (49.3)	103 (46.6)	207 (47.9)
	With axial load	52 (24.6)	55 (24.9)	107 (24.8)
	Without axial load	55 (26.1)	63 (28.5)	118 (27.3)

Values are means ± standard deviation in parentheses
No significant differences between groups on all variables

Compliance with PRECON

In the four week PRECON program 151 participants (71.6%) executed 10 or more training sessions. Thirty participants (14.2%) executed 7-9 training sessions and 14 participants (6.6%) trained 4-6 times. Sixteen participants (7.6%) of the PRECON group did not do any walking or hopping sessions at all.

Effect of the preconditioning program

The incidence of RRIs was 15.2% (26 of 171) in the PRECON group and 16.8% (32 of 191) in the control group. The difference in RRIs between both groups was not significant (X^2 = 0.161, df = 1, P = .69). Additional analyses (see Table 4) showed that the number of RRIs per 1000 hours was 31.0 (95% CI, 24-38) in the PRECON group and 30.0 (95% CI, 24-37) in the control group. Survival curves (Kaplan-Meier) were made for both training groups (figure 2). The difference in mean survival time between groups was not significant (p= 0.15).

Table 4 Incidence of RRIs in the preconditioning and control group

RRIs	**PRECON** (n=171)	**Control** (n=191)	**Total** (n=362)
Absolute number	26	32	58
Per 100 runners at risk	15.7 (10.3-21.2)	16.8 (11.5-22.1)	16.3 (12.5-20.1)
Per 1000 hours of exposure	31 (24.0-38.0)	30 (24.0-37.0)	32 (26.0-36.0)

RRIs, running-related injuries
Numbers in parentheses represent 95% confidence interval

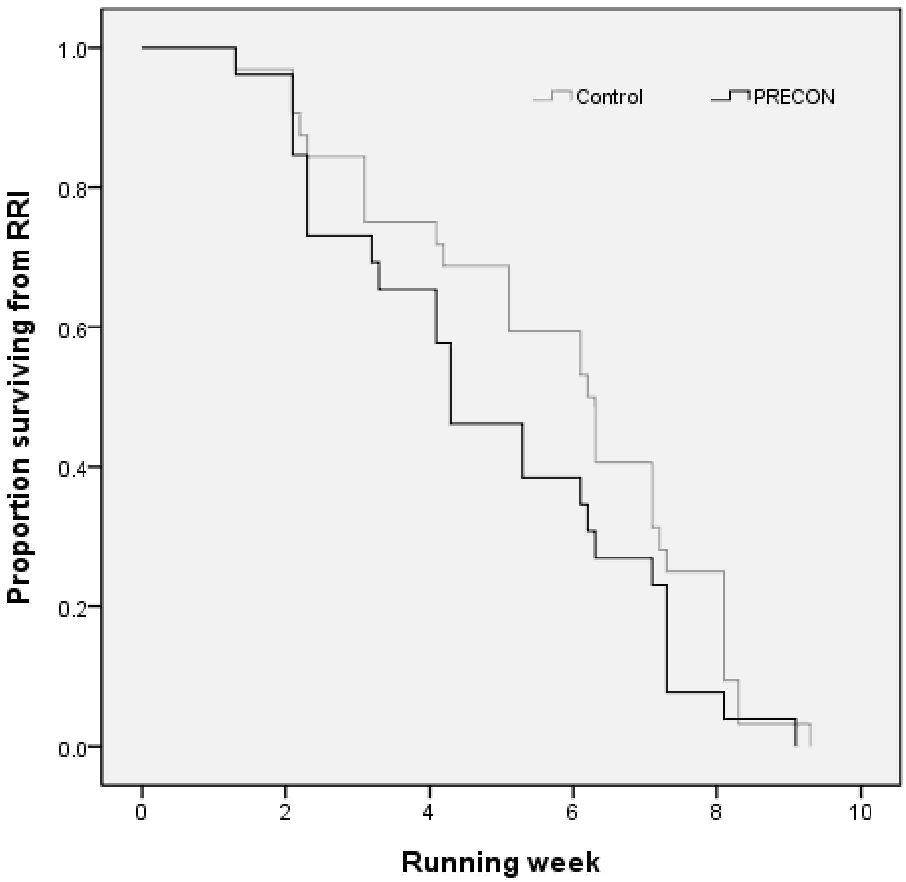

Figure 2. Kaplan-Meier plot of RRI survival for the PRECON and control groups in the 9-week program.

Occurrence of Running-Related Injuries

A total of 58 RRIs were recorded for both groups. Figure 3 illustrates the absolute number of RRIs per week in each training group. It shows that in the control group the most RRIs (n=18) were registered in the last four weeks of the nine week running program. The control group showed most RRIs in running week eight. In the PRECON group most injuries were seen in the second and fourth week of the nine week running program and in the sixth and eighth week when the four week PRECON program was combined with the nine week running program. Descriptive information on RRIs is shown in Table 5.

Table 5 Absolute number and percentage of RRIs per anatomical site per group

	PRECON	Control	Total
N	26	32	58
Hip/back	3 (11.5%)	6 (18.7%)	9 (15.5%)
Upper leg	1 (3.8%)	1 (3.1%)	2 (3.4%)
Knee	9 (34.6%)	14 (53.8%)	23 (39.7%)
Lower leg	10 (38.4%)	7 (21.9%)	17 (29.3%)
Ankle/foot	3 (11.5%)	4 (12.5%)	7 (12.1%)

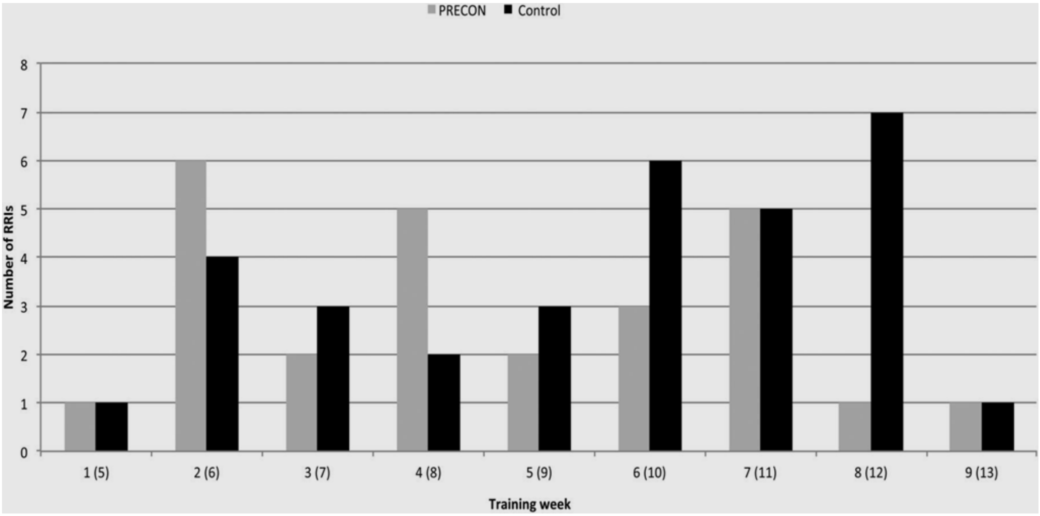

Figure 3: Number of RRIs per training week in the PRECON and control group. Between brackets ( ) weeknumbers including four week training program

Training characteristics

During the nine week running program participants of the control group completed more running minutes than participants in the PRECON group, respectively 329.7 ± 177.1 (67.3%) and 301.1 ± 184.7 (61.4%). This difference in exposure time between the PRECON and the control group was not significant. The exposure time until an RRI occurred was 149.5 (± 123.2) minutes in the PRECON group and 206.0 (± 156.5) for the control group ($p = 0.28$). The non-injured runners in the PRECON and control group completed respectively 328.3 and 354.6 minutes of running in the nine week program. Compliance with the nine week program, with a total exposure of 490 minutes of running, was respectively 67.0% and 72.4% (n.s.) of total running volume for the PRECON and control group.

Discussion

The results of the randomized controlled trial showed no effect of a four week preconditioning (PRECON) program on the incidence of RRIs. The incidence rate of RRIs was 15% in the PRECON group and 17% in the control group, and 31 RRIs per 1000 hours of running in the PRECON and 30 RRIs per 1000 hours in the control group.

Various reasons for the absence of an effect are conceivable. Firstly, the intervention period may have been too short to gain a positive adaptation. Looking at the program it could be argued that this is not a preconditioning program by definition but a preloading program and therefore the structural adaptations could longer to achieve an effect. Many studies on preconditioning used an intervention program of six weeks[24,26,27] or more.[22,23,28] All studies found a positive effect on the incidence of sports injuries. There is also evidence however, for effects of short preconditioning programs. The study of Knapik et al. showed that recruits who participated in a three or four week preconditioning program were at a lower injury risk than other recruits with the same fitness level.[25] One has to keep in mind that a preventive measure should be feasible and acceptable for participants.[32] When extending the preconditioning program by two to four weeks there is a chance that the essential nature or appeal of running may be affected, thereby resulting in less participation or compliance.[32]

Secondly, participants in the PRECON group had to execute walking and hopping exercises on their own. Preconditioning or pre-season program exercises done under supervision for proper execution or in a group showed greater effects than non-supervised or home-based programs.[33,34] Non-supervised exercise programs may also be less motivating and result in poorer compliance than a supervised and structured training program followed among a peer group.[34,35].

Compared to other studies the percentage of RRIs in the present study was relatively low (16%). In the literature the incidence of lower extremity running injuries ranges from 20.3% to 84.9%.[2,5,7-9,11,12,17,36] Care should be taken when interpreting these figures, because additional analyses show that the number of RRIs per 1000 hours running was 31 in the preconditioning group and 30 in the control group. Incidences in the literature vary from 3 to 59 RRIs per 1000 hours.[2-6]

The literature offers little information on the incidence of RRI among novice runners. The first GRONORUN study showed an injury incidence of 30 and 38 RRIs per 1000 hours of running.[4] That outcome is comparable with the incidence found in the present study. In the first GRONORUN study the risk of sustaining an RRI during a standard 8-week running program was compared to a graded 13-week running program. Another study that examined the risk of running injuries during a training program was the Vancouver Sun Run.[8] In a 13-week training protocol novice runners had to run in training sessions of 35 to 66 minutes three times a week. The injury incidence was 29.5 per 100 runners at risk. The number of RRIs per 1000 hours was unknown. Length of the running program and running frequency, that is, three times a week, were identical to those used in GRONORUN1. The predominant sites of RRIs shown in the literature were the knee and lower leg.[3,8,12,36] The results of the present study support these findings. The most frequently injured body parts were the knee (39%) and the lower leg (30%).

A limitation of this study is the low number of RRIs. Therefore the study could be underpowered and outcomes of this study should therefore be interpreted cautiously. Another limitation could be the self-registration of RRIs. The RRI was not systematically diagnosed by an independent healthcare professional, and this may have biased the primary outcome measure. A third limitation was that there was no information on the intensity of running in the training program. It is possible that a high percentage of the injured runners trained at too great of an intensity or duration for their level of fitness. Participants were instructed to run at a comfortable pace at which they could converse without breathlessness but this was not objectively measured. The nine week running program was based on minutes of running and not on distance. Training pace could have resulted in a different weekly training volume. A fourth limitation was the high number of participants that did not start running the nine week running program after inclusion. This may have affected study outcomes. A fifth limitation could be the self-reported adherence to the intervention program used to quantify compliance. Although the compliance looked high, this method of quantifying adherence carries a potential risk of bias.

The risk of an RRI will always be present among novice, recreational and competitive runners. A runner with an overuse RRI must have exceeded the stress-frequency curve in terms of running distance or intensity in a way that there is too little time for recovery or positive adaptation of the musculoskeletal system. Running causes a physiological or pathological adaptation to this mechanical loading, resulting in respectively a training effect or overuse injury. Besides training there has to be an underlying intrinsic, anatomical or biomechanical factor that will influence the stress frequency curve in a positive or negative direction. Preconditioning programs should consider the possibility for variation and progression in the prescribed exercises, which will avoid ceiling effects, enhance motivation among trainers and athletes and favor compliance.[35] The duration of a preconditioning program should be ideal: not too short, for a lack of training effect and adaptation, and not too long, to prevent boredom and dropout. Compliance should be carefully monitored because it is an important factor for the effect of a preventive measure. Exposure data should measure pace, speed, distance and intensity. With new portable running measurements systems with GPS sensors this should be possible even in a large study cohort. And last but not least, the effectiveness of an injury prevention program depends not only on its content but also on the success of its relatively permanent acceptance and implementation within the sports community among athletes, trainers, coaches and sport organizations.

In conclusion, this prospective GRONORUN 2 study demonstrated that a 4-week non-supervised preconditioning program with walking and hopping exercises had no influence on the incidence of RRIs in novice runners preparing for a four mile recreational running event. This was, to our knowledge, the first preconditioning study in running. Attention should be paid to type of exercise, duration, progression and program variation in order to promote compliance and efficacy. Exposure in running should be monitored carefully in terms of speed, intensity and duration. Even though it may be comparable to the quest for the Holy Grail further studies on modifiable risk factors and prevention of running injuries need to be performed to better advise runners in the future.

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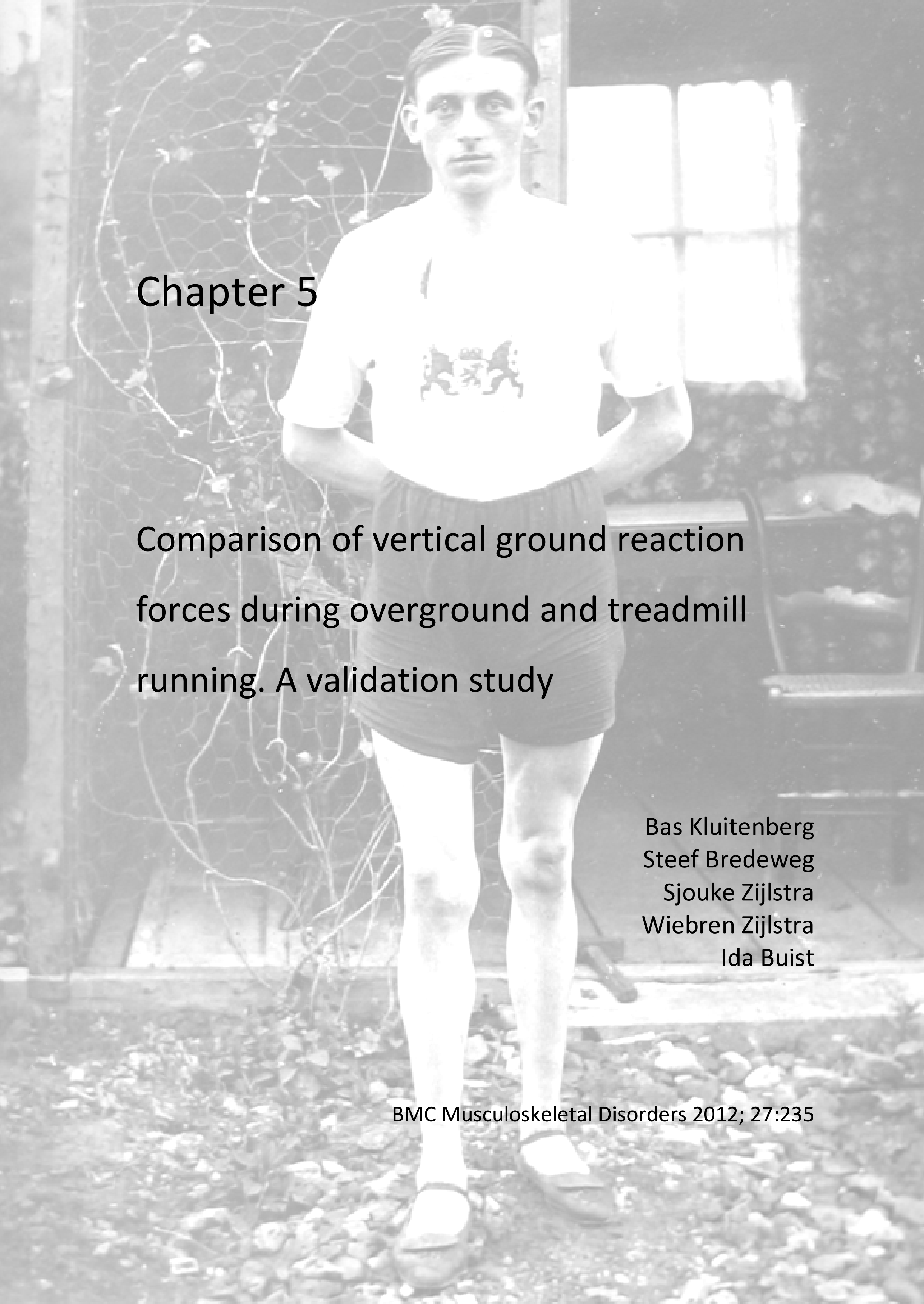

Chapter 5

Comparison of vertical ground reaction forces during overground and treadmill running. A validation study

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Abstract

Background: Ground reaction forces are often associated with running related injuries, because of the high forces applied to the ground with each foot strike. Ground-reaction forces are generally measured with a ground-mounted force platform. During running, however, these overground measurements have some practical issues. An instrumented force measuring treadmill can overcome the shortcomings inherent to overground testing. The purpose of the current study was to determine the validity of an instrumented force measuring treadmill for measuring vertical ground-reaction force parameters during running.

Methods: Vertical ground-reaction forces of experienced runners (12 male, 12 female) were obtained during overground and treadmill running at slow, preferred and fast self-selected running speeds. For each runner, 7 mean vertical ground-reaction force parameters of the right leg were calculated based on five successful overground steps and 30 seconds of treadmill running data. Intraclass correlations ($ICC_{(3,1)}$) and ratio limits of agreement (RLOA) were used for further analysis.

Results: Qualitatively, the overground and treadmill ground-reaction force curves for heelstrike runners and non-heelstrike runners were very similar. Quantitatively, the time-related parameters and active peak showed excellent agreement (ICCs between 0.76 and 0.95, RLOA between 5.7% and 15.5%). Impact peak showed modest agreement (ICCs between 0.71 and 0.76, RLOA between 19.9% and 28.8%). The maximal and average loading-rate showed modest to excellent ICCs (between 0.70 and 0.89), but RLOA were higher (between 34.3% and 45.4%).

Conclusion: The results of this study demonstrated that the treadmill is a moderate to highly valid tool for the assessment of vertical ground-reaction forces during running for runners who showed a consistent landing strategy during overground and treadmill running. The high stride-to-stride variance during both overground and treadmill running demonstrates the importance of measuring sufficient steps for representative ground-reaction force values. Therefore, an instrumented treadmill seems to be suitable for measuring representative vertical ground-reaction forces during running.

Background

Running is a popular sport which is practiced by many people for its positive health effects. On the contrary, up to 79% of the runners annually suffer from the negative side effects of running, injuries.[1] Overuse injuries of the lower extremity, such as stress fractures, iliotibial band friction syndrome, patello femoral pain, plantar fasciitis, and Achilles tendinopathy are common injuries sustained among runners.[2] Various risk factors for running related injuries have been proposed, these risk factors can be divided into three categories: training, anatomical and biomechanical factors.[3] Of the biomechanical factors, ground reaction forces (GRFs) are often associated with running related injuries, because of the high forces applied to the ground with each foot strike. Several studies examined the relation between GRFs and running related injuries, however the nature of this association remains unclear.[2,4,5] Most runners are heelstrike runners and make first ground contact with the posterior part of the foot. This running style results in a typical vertical GRF force-time curve that is characterized by two peaks, the impact peak and the active peak, as depicted in figure 1. Magnitude of the impact peak is speed dependent and occurs during the first 10% of stance (10-30ms).[3] The active peak is reached approximately during mid-stance and can last up to 200ms. The absence of a separate impact peak in the force-time curve is typical for a non-heelstrike runner, as depicted in figure 1.[6] Besides a vertical component, GRFs also have an anterior-posterior and medio-lateral component. During running, the anterior-posterior force component shows a typical braking and propulsive phase while the medio-lateral force component is characterized by more variability.[7] Compared to the vertical GRF component, anterior-posterior and medio-lateral forces are small.[7] Therefore, the vertical GRF component is often associated with running related injuries.

GRFs are generally measured with a ground-mounted force platform. During running, however, these overground force platform measurements have some practical issues. The limited length of a walkway makes it difficult to simulate natural running at a constant speed in a laboratory situation.[8] Since a force platform is only capable of measuring GRFs of one single stance phase per trial, it is time consuming to measure GRFs of multiple steps.[9,10]

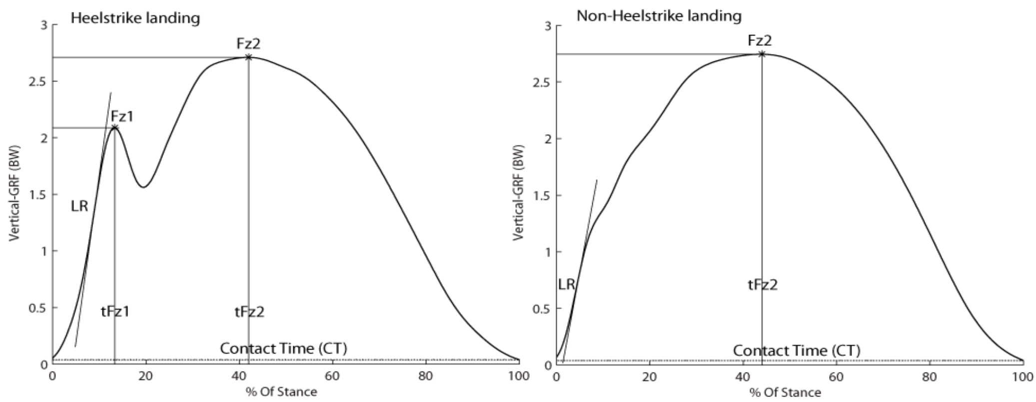


Figure 1: Outcome measures in a typical vertical ground-reaction force (GRF) curve for a heelstrike runner and a non-heelstrike runner. Figure is created from personal data.

For detection of small differences in GRFs during running, however, it is important to record sufficient trials.[11] An instrumented treadmill capable of measuring GRFs can overcome the limitations inherent to overground GRF testing during running at a short walkway and thereby help to elucidate the relation between GRFs and running related injuries. With an instrumented treadmill it is possible to measure GRFs of multiple steps during one trial without interruptions in running speed, resulting in a more stable running pattern during the measurements.[8] An underlying assumption when using a treadmill for running analysis is that running on a treadmill is similar to overground running. A comparison of spatio-temporal variables during overground and treadmill running was made in several studies. During treadmill running, runners tend to run with a shortened stride length and an increased stride rate.[8,12,13] Despite of these spatio-temporal differences, only small differences in knee flexion and a more flattened landing style during treadmill running were observed.[8,14] An overground-treadmill comparison with respect to GRFs was made in only two studies. No systematic errors or extraordinary differences in vertical GRFs were found.[8,9] Impact peaks and loading rates, however, have not been studied in these previous studies.

The purpose of this study was to determine the validity of a custom made instrumented force measuring treadmill to measure vertical GRF parameters during running. Validation of the treadmill was performed by comparing overground and treadmill measured vertical GRF parameters during running.

Methods

Participants

Twenty-four experienced runners (12 male, 12 female) between 18 and 35 years old participated in this study. The runners were voluntarily recruited by contacting two local track and field clubs. The criteria for inclusion in this study included a minimal training frequency of two times a week for at least a period of one year. Runners who reported an injury at time of measurement were excluded. Both heelstrike and non-heelstrike runners were allowed to participate in this study. All participants signed an informed consent before measurements started. The study was approved by the Medical Ethical Committee at the University Medical Center Groningen, The Netherlands; M12.112668.

Overground measurements

During the overground measurements, GRFs were measured at three different individual speed conditions. Participants were instructed to run at their preferred speed (running speed for a normal endurance run), slower speed (running speed during a warming-up), and a faster speed (10km race speed) respectively. GRFs were collected with a force platform (0.60m x 0.40m) which was mounted in the middle of a 17.5m long runway and had a sample frequency of 1000Hz. Running speed was monitored with two pairs of photocells placed 2.5m before and after the force platform.

Before the actual overground measurements started, the participants performed several accommodation runs. During these accommodation runs, the exact start position for the measurements was determined. The start position was based on the position of foot placement at the force platform. Foot strike of the right foot should be completely at the force platform without an alteration in running pattern. An alteration can indicate aiming for the force platform, which modifies the GRF pattern.[15] Position of foot placement and running pattern were evaluated on sight. When participants were able to run several trials at the same speed, while landing with the right foot completely placed at the force platform, without visible alterations in running pattern, the actual measurements started. Since the participants were tested at three different speed conditions, accommodation runs were performed for each speed condition (preferred, slow and fast). The accommodation runs for the preferred speed were combined with a short warming-up and took longer (approximately 10 min), where the subsequent accommodation runs took approximately 5 minutes.

During the actual measurements, GRF data were captured until five clean strikes of the right leg within a 5% speed range were recorded for all speed conditions. Trials with visible alterations in running pattern were not included in these five clean strikes. Afterwards, the mean running speed of the five steps was calculated for each speed condition.

Table 1: Definition of outcome measures, as displayed in figure 1.

Outcome measure	Description
Fz1	Local maximum in the vertical GRF data, normalized to body weight (BW).
Fz2	Maximum value in the vertical GRF data, normalized to BW.
LR	The steepest part of the vertical GRF curve, from stance to impact peak. Expressed in BW/s.
ALR	Average loading rate, the slope of the line from 20% to 80% of Fz1. Expressed in BW/s.
tFz1	Time from heelstrike to Fz1 in ms.
tFz2	Time from heelstrike to Fz2 in ms.
CT	Contact time, from heelstrike to toe-off in ms.

Outcome measures for the overground and treadmill data were identified with the same routine. Foot strikes were detected with a threshold of 30 Newton for both heelstrike and toe-off.

Treadmill measurements

An instrumented treadmill (Entred, Forcelink, Culemborg, The Netherlands) with a running surface of 1.60m by 0.60m which was equipped with three force transducers (ACB-500kg, Vishay Revere Transducers, Breda, The Netherlands) was used to measure vertical GRFs during treadmill running (figure 2). GRFs were collected with a sample frequency of 1000Hz.

Before the treadmill measurements started, participants started with an accommodation run of 10 minutes at 10 km·h^{-1}. After this accommodation period, participants were tested at three different individual speed conditions (slow, preferred and fast). Treadmill speed was matched to the average overground running speed for each speed condition because GRF parameters are speed dependent.[7] The three speed conditions lasted three minutes and were offered in random order. GRFs were recorded during the last 30 seconds of each speed condition. When treadmill measurements were finished, participants were given the opportunity for cooling-down at the treadmill. All measurements were conducted while participants were running in their personal running shoes.

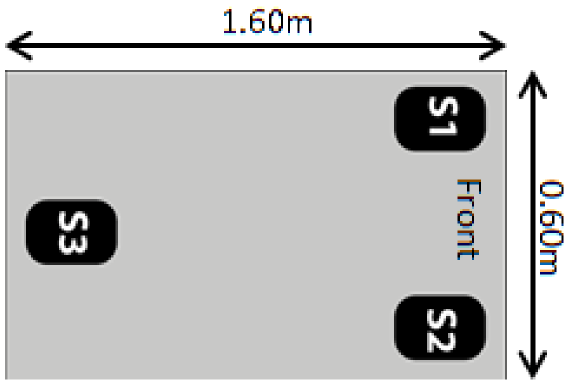


Figure 2: position of the force transducers (S1, S2 and S3) inside the instrumented treadmill.

Data analysis

Vertical force data from both the force platform and the treadmill were processed using custom programs written in MATLAB R2010a (The MathWorks, Inc, Natick, MA). A 13-point moving average filter was used to filter the GRF data that was recorded during the overground and treadmill measurements. Foot strikes in the overground and treadmill data were detected with a threshold of 30 Newton for impact and toe-off phase. Outcome measures for all right foot steps were identified, as described in table 1. For each speed condition outcome measures of each participant were averaged. A distinction between heelstrike and non-heelstrike landing patterns was made based on the existence of an impact peak Fz1. Peak values Fz1 and Fz2 and the loading-rate were normalized to bodyweight.

Statistical analysis

A within-subject repeated measures design was used to determine the validity of the instrumented treadmill for measuring vertical GRF parameters during running. Therefore, a two-way mixed-effects, consistency, single measure intraclass correlation coefficient ($ICC_{(3,1)}$) model was used to examine the agreement between overground and treadmill measured GRF-parameters. Interpretation of the intraclass coefficients were as follows: poor (0 – 0.39), modest (0.4 – 0.74), or excellent (0.75 – 1).[16] ICCs were calculated by using SPSS (SPSS inc. Version 18.0, Chicago, IL, U.S.A.). Besides the intraclass correlations, Bland-Altman plots were used to examine the agreement between overground and treadmill measurements.[17] These plots were made for each outcome measure and each speed condition. The limits of agreement (LOA) were calculated (mean difference +/- 1.96 times the standard deviation of the difference). Also ratio limits of agreement (RLOA) were calculated to express the LOA as percentage of the mean overground-treadmill value. The upper and lower LOA and the RLOA provide insight into how much random variation may be influencing the measurements.

Results

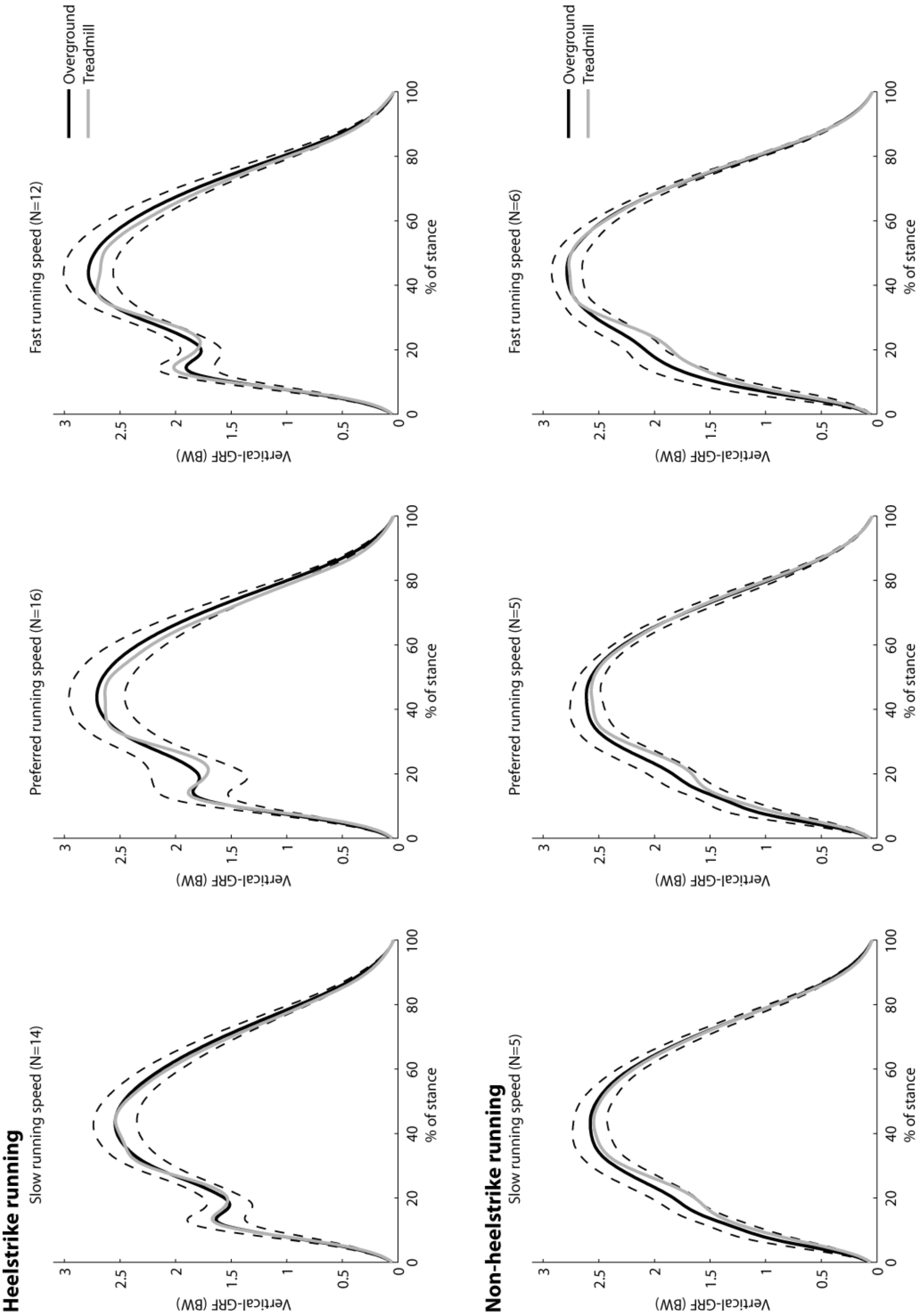
In table 3 characteristics of the participants of this study are shown. Ground-reaction force (GRF) parameters of a different landing strategy cannot be compared, therefore only GRF parameters of participants who showed a consistent landing strategy during overground and treadmill running within a speed condition were examined. During both the overground and treadmill measurements at preferred running speed, 16 participants showed a consistent heelstrike (HS) landing and 5 participants a consistent non-heelstrike (NHS) landing. At the slow running speed measurements, a consistent HS landing was observed in 14 participants and 5 participants showed a consistent NHS landing. Twelve runners showed a consistent HS landing during overground and treadmill running at fast running speed, while 6 participants consistently used a NHS landing strategy.

Table 2: Subject characteristics

	Male (N=12) Mean ± SD	**Female (N=12)** Mean ± SD	**Total (N=24)** Mean ± SD
Age (year)	23.3 ± 2.7	22.1 ± 2.0	22.7 ± 2.4
Length (cm)	184.5 ± 8.5	173.7 ± 4.9	179.1 ± 8.8
Weight (kg)	69.8 ± 5.6	62.2 ± 6.8	66.0 ± 7.2
Upper leg length (cm)	44.5 ± 2.7	41.3 ± 3.5	42.9 ± 3.5
Lower leg length	50.5 ± 3.4	47.8 ± 3.0	49.1 ± 3.4
Weekly training (times/week)	3.3 ± 1.2	2.7 ± 0.8	3.0 ± 1.1
Weekly km (km/week)	35.2 ± 22.1	23.8 ± 10.7	29.5 ± 18.0
Speed 1 (km/h)	11.9 ± 0.8	10.2 ± 1.1	11.0 ± 1.3
Speed 2 (km/h)	13.9 ± 0.7	11.3 ± 0.9	12.6 ± 1.5
Speed 3 (km/h)	15.7 ± 0.8	12.7 ± 1.3	14.2 ± 1.9

Speed 1: slow speed condition, speed 2: preferred speed condition, speed 3: fast speed condition.

Qualitatively, the overground and treadmill GRF curves for both HS and NHS running at slow, preferred and fast running speeds, were very similar, as can be seen in figure 2.


Heelstrike running
Slow running speed (N=14)
Preferred running speed (N=16)
Fast running speed (N=12)
Non-heelstrike running
Slow running speed (N=5)
Preferred running speed (N=5)
Fast running speed (N=6)
Overground
Treadmill
Vertical-GRF (BW)
% of stance

In table 3 a quantitative evaluation of the vertical GRF-parameters of both HS and NHS runners can be found. The levels of agreement between overground and treadmill running for the time related variables (tFz1, tFz2 and CT) were excellent (ICCs between 0.76 and 0.95 and RLOAs between 5.7% and 15.5%). Also the active peak (Fz2) measured with both devices showed excellent agreement (ICCs between 0.77 and 0.89, RLOAs between 7.8% and 9.9%). Modest agreement was found for the impact peak, Fz1 (ICCs between 0.71 and 0.76, RLOAs between 19.9% and 28.8%). Maximal loading rate (LR) and average loading rate (ALR) also showed modest to excellent intraclass correlations (ICCs between 0.70 and 0.89), however the ratio limits of agreement were higher (RLOA values between 34.3% and 45.4%).

Table 3: Outcome measures for overground and treadmill running. Intraclass correlations, mean-differences with limits of agreement (LOA), and ratio limits of agreement (RLOA) were reported. Both HS and NHS runners were taken into account in the statistical analysis. Number of participants: HS (slow: N=14, preferred: N=16, fast: N=12), NHS (slow: N=5, preferred: N=5, fast: N=6).

		OG Mean ± SD	TM Mean ± SD	$ICC_{(3,1)}$ (95%CI)	Mean diff (LOA) diff (lowLim, upLim)	RLOA (%)
Fz1 (BW)						
HS	Slow	1.67 ± 0.26	1.70 ± 0.23	0.74 (0.37, 0.91)	0.03 (-0.32, 0.38)	20.8
	Pref	1.94 ± 0.45	1.93 ± 0.30	0.71 (0.35, 0.89)	-0.01 (-0.57, 0.55)	28.8
	Fast	1.94 ± 0.25	2.06 ± 0.32	0.76 (0.35, 0.92)	0.12 (-0.28, 0.52)	19.9
Fz2 (BW)						
HS	Slow	2.54 ± 0.20	2.53 ± 0.18	0.77 (0.49, 0.91)	-0.02 (-0.27, 0.23)	9.9
	Pref	2.70 ± 0.26	2.65 ± 0.25	0.89 (0.76, 0.96)	-0.03 (-0.25, 0.17)	7.9
	Fast	2.77 ± 0.24	2.70 ± 0.22	0.86 (0.67, 0.95)	-0.06 (-0.27, 0.15)	7.8
NHS	Slow	2.56 ± 0.17	2.55 ± 0.20			
	Pref	2.61 ± 0.15	2.58 ± 0.13			
	Fast	2.79 ± 0.15	2.78 ± 0.20			
LR (BW/s)						
HS	Slow	81.11 ± 25.62	87.28 ± 23.39	0.76 (0.47, 0.90)	3.25 (-28.62, 35.12)	39.9
	Pref	95.34 ± 26.67	105. 33 ± 25.08	0.80 (0.57, 0.91)	6.11 (-26.21, 38.42)	34.3
	Fast	104.40 ± 29.29	118.08 ± 33.73	0.70 (0.36, 0.88)	7.17 (-37.69, 52.02)	42.7
NHS	Slow	70.03 ± 14.68	65.09 ± 13.74			
	Pref	77.00 ± 22.35	74.25 ± 16.47			
	Fast	95.81 ± 26.02	87.41 ± 18.74			
ALR (BW/s)						
HS	Slow	68.89 ± 20.26	73.92 ± 20.22	0.84 (0.63, 0.93)	2.98 (-24.74, 30.70)	45.3
	Pre	82.14 ± 21.38	88.70 ± 20.75	0.89 (0.74, 0.95)	3.60 (-23.01, 30.21)	36.4
	Fast	90.70 ± 23.66	100.77 ± 29.10	0.86 (0.67, 0.95)	4.08 (-31.26, 39.42)	45.4
NHS	Slow	33.96 ± 6.07	31.21 ± 5.01			
	Pre	47.09 ± 22.92	33.78 ± 4.20			
	Fast	43.63 ± 13.89	36.00 ± 4.20			
tFz1 (ms)						
HS	Slow	35 ± 4	35 ± 4	0.76 (0.40, 0.92)	0.0 (-5.4, 5.4)	15.5
	Pre	34 ± 4	34 ± 3	0.82 (0.56, 0.93)	0.3 (-4.4, 5.0)	13.8
	Fast	32 ± 5	33 ± 4	0.87 (0.61, 0.96)	0.6 (-3.7, 4.8)	13.0
tFz2 (ms)						
HS	Slow	112 ± 13	109 ± 10	0.84 (0.63, 0.94)	-1.8 (-15.4, 11.8)	12.6
	Pref	102 ± 13	100 ± 12	0.94 (0.85, 0.97)	-1.6 (-10.1, 6.8)	8.5
	Fast	99 ± 10	96 ± 11	0.87 (0.68, 0.95)	-3.0 (-13.5, 7.5)	11.0
NHS	Slow	102 ± 13	103 ± 15			
	Pre	99 ± 12	98 ± 11			
	Fast	92 ± 8	91 ± 10			
CT (ms)						
HS	Slow	258 ± 22	254 ± 21	0.92 (0.80, 0.97)	-4.0 (-21.4, 13.4)	6.9
	Pre	232 ± 23	232 ± 20	0.92 (0.82, 0.97)	-2.0 (-17.2, 13.2)	6.6
	Fast	223 ± 21	220 ± 21	0.95 (0.87, 0.98)	-3.3 (-15.6, 9.1)	5.7
NHS	Slow	240 ± 17	237 ± 19			
	Pref	229 ± 12	222 ± 12			
	Fast	213 ± 12	206 ± 12			

HS: Heelstrike-runner, NHS: Non-Heelstrike-runner, CI: Confidence Interval, LOA: Limit of Agreement, RLOA: Ratio Limit of Agreement, OG: Overground, TM: Treadmill, BW: Body Weight.
Slow running speed: HS runners: 11.0 ± 1.3 km·h^{-1}, NHS runners: 10.9 ± 1.5 km·h^{-1}
Preferred running speed: HS runners: 12.7 ± 1.6 km·h^{-1}, NHS runners: 11.8 ± 1.5 km·h^{-1}
Fast running speed: HS runners: 14.1 ± 2.0 km·h^{-1}, NHS runners: 13.9 ± 1.9 km·h^{-1}

Discussion

The instrumented treadmill is capable of measuring vertical ground-reaction forces (GRFs) during running and seems to be a usable tool for simulating overground running kinetics. The results of this study demonstrated that the instrumented treadmill is a highly valid tool for the assessment of the vertical GRF parameters: tFz1, tFz2, CT and Fz2 and moderately valid for the assessment of Fz1, LR and ALR for runners who showed a consistent landing strategy during overground and treadmill running. A qualitative evaluation of the overground and treadmill vertical GRF curves as shown in figure 2, demonstrated that the vertical GRFs for both the heelstrike (HS) runners and the non-heelstrike (NHS) runners were similar during overground and treadmill running. The excellent intraclass correlations and low limits of agreement for contact time (CT), time to impact peak force (tFz1) and time to the active peak (tFz2) reflect this qualitative similarity. After all, these parameters show that the timing of peak values in the vertical GRF curve is not different for overground and treadmill running. The qualitative similarity of these GRF curves was also observed in other studies.[8,9] In the current study, the overground and treadmill measured active peak (Fz2) showed no noteworthy differences. This is in accordance with the results of Riley et al., who also compared overground and treadmill running kinetics in a group of 20 runners.[8] Overground and treadmill measured impact peaks (Fz1), maximal loading rates (LR) and average loading rates (ALR), showed less consistent results with modest to excellent intraclass correlations and wider limits of agreement. To our knowledge this study is the first to compare overground and treadmill measured impact peaks and loading rates during running, therefore it is not possible to evaluate these results with previous studies.

For an overground-treadmill comparison with respect to vertical GRF parameters, a consistent landing strategy during both running conditions (overground and treadmill) is required. While most runners showed a consistent landing strategy during overground and treadmill running, some runners switched to another landing strategy. These inconsistent runners mostly switched from an overground HS landing to a NHS landing during treadmill running. Considering that this behavior is in line with the more flattened landing style as observed in a previous study,[18] it is likely that these inconsistencies in landing strategy are the result of accommodation to treadmill running. The results of this study demonstrated that the inconsistencies in landing strategy are smallest during running at preferred speed. Therefore, to maximize certainty, it can be recommended to determine landing strategy with a treadmill measurement at preferred running speed.

The use of a treadmill in a research setting has been subject of much debate. Several factors are mentioned which may cause biomechanical differences between overground and treadmill running.[13] First, non-mechanical factors as accommodation to the changed visual and auditory surroundings or fear during treadmill running may result in differences between overground and treadmill running biomechanics.[19] Second, differences in air resistance may have an effect on treadmill running form.[20] The effects of air resistance on running kinematics, however, will only be visible during running at high speeds.[21] Third, intra-stride belt speed variations, due to an energy exchange between the treadmill and the runner, can cause differences in running kinematics compared to overground running. In particular low powered treadmills are more sensitive for opposite forces acting on the belt during running, resulting in larger belt speed variations. These variations in belt speed may lead to biomechanical differences during treadmill running when compared to overground running.[19] Fourth, during running, leg stiffness is adjusted to the stiffness of the running surface.[22] Adjusting leg stiffness results in subtle changes in the kinematics of the lower extremity.[23] Therefore, differences in running surface may lead to biomechanical differences when comparing overground and treadmill running.

Several studies compared overground and treadmill running biomechanics.[8,12,18] Even though runners tend to run with a shortened stride length and an increased stride rate during treadmill running,[8,12,13] overground and treadmill running kinematics are remarkably similar.[8,13,18] Only small differences in knee and ankle joint kinematics were reported. Nigg et al. observed a more flattened landing style during treadmill running.[18] Riley et al. did not find differences in ankle joint kinematics, but did find differences in minimal and maximal knee flexion.[8] Maximal knee flexion was lower and minimal flexion was higher during treadmill running, which could be a result of the observed decrease in flight phase and higher stride rate.[8] Thus, despite the theoretical factors which may influence treadmill running biomechanics, only small differences in overground and treadmill kinematics were observed. In the current study, also no abnormal differences in GRF parameters between overground and treadmill running were found. These findings are in line with previous studies where overground and treadmill running kinetics were compared.[8,9] Besides the high between person variance in Fz1, LR and ALR during both overground and treadmill running, as can be seen in table 2 and figure 2, also stride-to-stride variance for these parameters was high. These high stride-to-stride variances in Fz1, LR and ALR demonstrate the importance of measuring sufficient steps for representative GRF values. This is especially important for detecting small differences between different conditions or persons.[24] Because a treadmill makes it possible to measure multiple steps during one test trial, it can be argued that a treadmill measurement is more suitable for detecting small differences in vertical GRFs during running. However, this assumption was not assessed in the current study.

A limitation of this study was that participants first performed the overground measurements after which the treadmill measurements started. Due to this fixed order of the measurements, fatigue may have influenced the later treadmill measurements.[25] Nevertheless, this influence is expected to be low, since all participants were experienced runners who did not have to deliver a maximal performance and participants did not show signs of exaggerated fatigue during the measurements.

Conclusion

The results of this study demonstrated the treadmill is a moderate to highly valid tool for the assessment of vertical GRFs during running for runners who showed a consistent landing strategy during overground and treadmill running. Therefore, an instrumented treadmill can be used to measure vertical GRF parameters which correspond to normal overground values during running.

In a future study, the treadmill can be used to measure vertical GRF parameters in a large group of runners, for instance to identify possible kinetic risk-factors for running related injuries prospectively.

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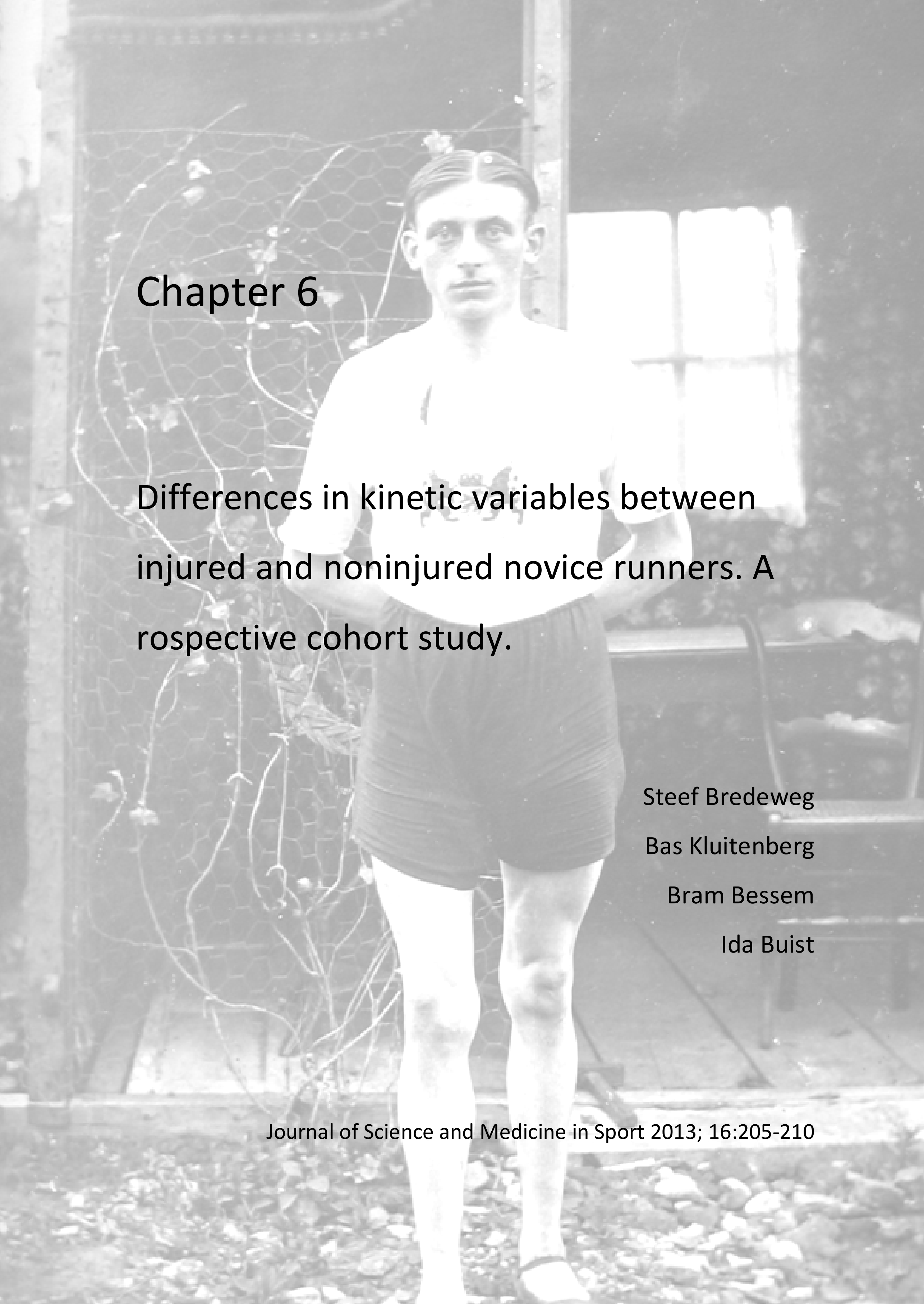

Chapter 6

Differences in kinetic variables between injured and noninjured novice runners. A rospective cohort study.

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Abstract

Objectives: This prospective study examined differences in kinetic variables between injured and noninjured novice female and male runners and its potential contribution to RRIs.

Design: A prospective cohort study.

Methods: At baseline vertical ground reaction forces were assessed with an instrumented treadmill equipped with three force measuring transducers. Female participants ran at 8 and 9 $km \cdot h^{-1}$ and male runners ran at 9 and 10 $km \cdot h^{-1}$. Primary outcome measure was a running related injury (RRI). Participants were novice female and male recreational runners and were followed during a 9-week running program with three running sessions a week.

Results: One hundred thirty three female and seventy seven male runners participated in this study. Mean age was 37.2 years and the BMI was 23.9 $kg \cdot m^{-2}$. During the nine week running program 16.2% of the participants sustained an injury and no difference in incidence between female and male runners was seen. In injured male runners loading rate was significantly higher compared to noninjured male runners at both running speeds and contact time in the injured male group was significantly shorter at 9 $km \cdot h^{-1}$. In the group of female injured and noninjured runners no differences on kinetic or spatio-temporal variables were observed. Female runners had significantly higher loading rates compared to male runners but this did not have an effect on the incidence of RRIs.

Conclusion: This study showed that male injured runners had higher loading rates and shorter contact times than noninjured male runners. In female runners, however, no differences in kinetic or spatio-temporal variables were observed between injured and noninjured novice runners.

Introduction

Nowadays, one of the most popular physical activities is running and its popularity is still growing. The health benefits of running are well known, however the occurrence of running-related injuries (RRIs) is high. Various epidemiological studies have estimated that 19 to 83 percent of the recreational and competitive runners sustain an RRI over a one year period.[1-3]

Most RRIs are overuse injuries located at the lower extremities[1,3,4]. Medial tibial stress syndrome, patellofemoral pain syndrome, iliotibial band syndrome, stress fractures of the tibia, fibula or metatarsals, plantar fasciitis, Achilles tendinopathy are common RRIs and could all be classified as overuse injuries[5,6]. Overuse injuries occur when the repetitive load is causing too much stress or the recovery time between training sessions is too short[7]. In this situation the musculoskeletal system cannot adapt to the applied load resulting in an overuse injury[7,8].

Various risk factors for RRIs have been studied but most studies on these factors showed inconsistent or conflicting results[2,6]. Potential risk factors for lower extremity RRIs are greater weekly training distance, history of previous injuries, lack of running experience, and running to compete[2,9]. Risk factors for RRIs can be divided into three categories; training (running frequency, duration, intensity, speed and distance), anatomical (foot type, ankle range of motion, leg length discrepancy) and biomechanical factors[7].

Biomechanical risk factors in running can be divided in kinetic and kinematic variables. Many studies have investigated the injury potential of kinematic variables, like magnitude and rate of foot pronation[10]. Kinetic variables that have been linked to overuse injuries are the impact peak[7,11,12], the active peak[12-14], and the loading rate[12,15,16]. These studies delivered contradictory results between kinetic variables and musculoskeletal overuse injuries. A major shortcoming of most of these studies was the retrospective nature and therefore no definite conclusion could be drawn. The only prospective study, the thesis of Bahlsen[17], found that runners with high peak impact forces and high loading-rates had significantly fewer RRIs. Because of these conflicting results and the scarcity of prospective studies there is a need for more research to examine the relation between RRIs and kinetic factors.

The importance of studying the possible relationship between kinetic factors and RRIs is three-fold. Firstly runners at risk could be easily identified by measuring kinetic variables. Secondly, preventive measures such as the use of insoles or shoe modifications could be developed and introduced to diminish the detrimental effects of causative kinetic factors on the development of RRIs[11]. And thirdly running technique could be modified in a way to reduce the load to the lower extremity and thereby decrease the risk of an RRI[18].

The purpose of this prospective study was to examine the differences in kinetic factors between injured and noninjured novice female and male runners and its potential contribution to RRIs. It was hypothesized that novice runners with a higher impact peak, active peak and loading rate sustained more injuries.

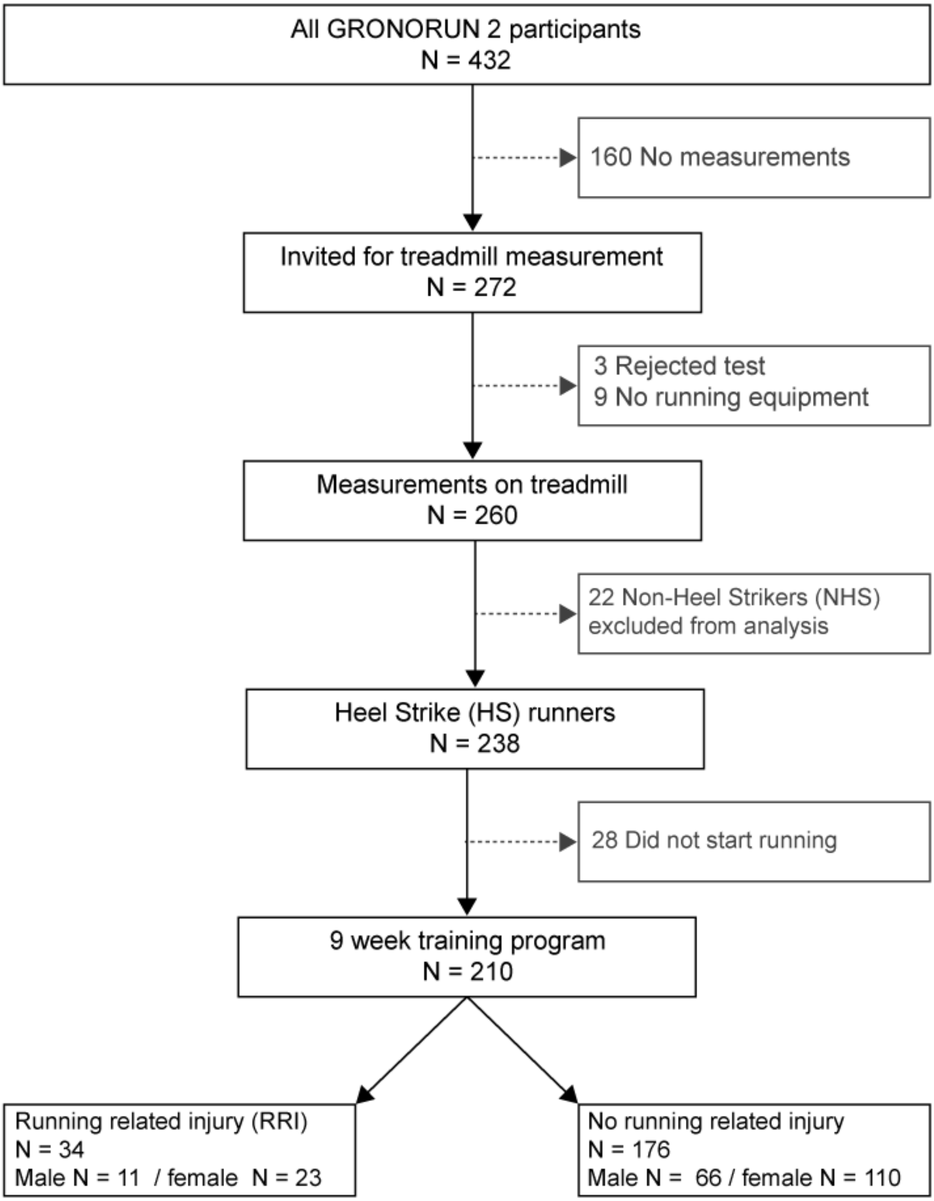
Methods

Novice runners, age 18 – 65 years, were recruited from the GRONORUN 2 population[19]. The GRONORUN 2 study was a randomized controlled trial which studied the effect of a preconditioning program on the incidence of RRIs in novice runners. The participants flow for this study can be found in figure 1. After baseline measurements and informed consent, participants were randomly assigned to the 4 week preconditioning program group or the control group. After inclusion in the GRONORUN 2 study a random selected group of participants was asked to participate in the treadmill running test. Before data collection, each participant signed a written informed consent. The study design, procedures, and informed consent procedure were approved by the Medical Ethics Committee of the University Medical Center Groningen, The Netherlands; 2007.217

All novice runners were tested on two running speeds for one minute on the instrumented treadmill. After 5 minutes of walking (5 $km \cdot h^{-1}$) on the treadmill female runners were tested at a running speed of 8 and 9 km·h^{-1} and male runners were tested on a running speed of 9 and 10 km·h^{-1}. Treadmill speeds were chosen on the basis of the average running speed in the Groningen 4-mile recreational run. In previous years the average finish time for recreational female and male runners was respectively 45 minutes and 40 minutes. Treadmill speed was fixed because kinetic factors are speed dependent[20.29] and for novice runners it might be difficult to determine their comfortable self-selected running speed. During the measurement participants were running on their own running shoes. The right leg length was measured from ground to greater trochanter while standing and wearing shoes using a telescopic measuring rod.

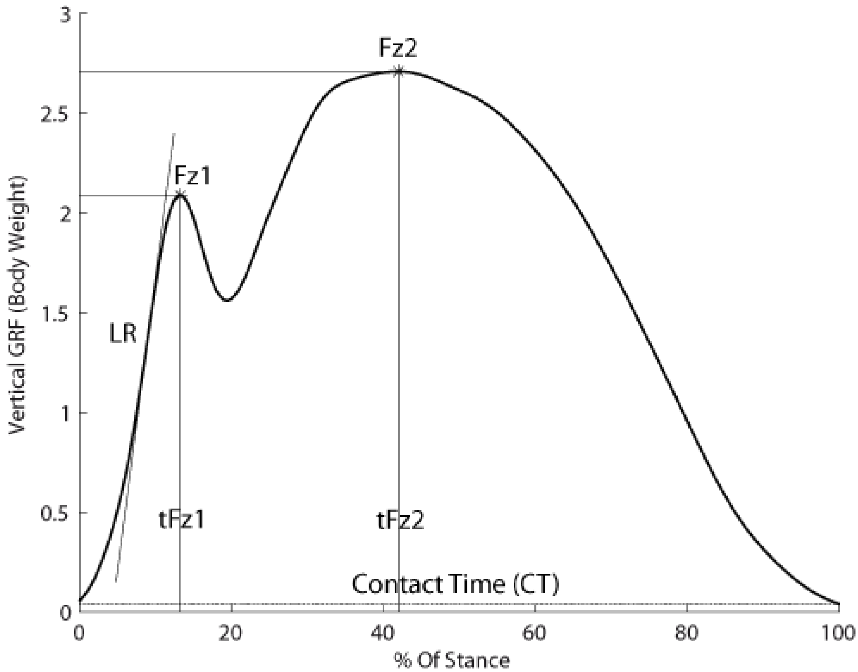
Vertical components of the ground reaction forces (VGRF) were measured (figure 2) on the instrumented treadmill. Stride length, step frequency and contact time were calculated from the ground reaction force data.

Figure 1 Flow chart for study population



The instrumented treadmill used in this study (Entred, Forcelink, Culemborg, the Netherlands), had a stiff running surface of 1.60m in length and 0.60m in width, and was driven by a 1.8 kW motor. The treadmill was equipped with three force transducers (ACB-500kg, Vishay Revere Transducers, Breda, the Netherlands) which had a sample frequency of 1000Hz and were connected to bridge amplifiers. The signals from the amplifiers were digitized into a 16-bit signal by an AD converter (PCI-6220, National Instruments, Austin, TX, USA) and were connected to a computer.

Figure 2 Graphic representation of the vertical ground-reaction force curve of a heelstrike runner. LR = Loading Rate, CT = Contact Time, Fz1 = Impact peak, Fz2 = Active peak, tFz1 = time to Fz1, tFz2 = time to Fz2. Figure is created from personal data.



In a recent study the treadmill was validated using a Bertec force platform (0.60m x 0.40m) mounted in the middle of a 17.5m long runway. Intra class correlations were obtained for impact peak (Fz1): 0.71 (95% CI: 0.35-0.89), active peak (Fz2): 0.89 (95% CI: 0.76-0.96), Loading rate (LR): 0.80 (95% CI: 0.57-0.91), time to Fz1: 0.82 (95% CI: 0.56-0.93), time to tFz2: 0.94 (95% CI: 0.85-0.97) and contact time (CT): 0.92 (95% CI: 0.82-0.97).

Vertical force data from the treadmill were processed using custom programs written in MATLAB R2010a (The MathWorks inc, Natick, MA). A moving average filter was used to filter the VGRF data that was captured during the treadmill run. Foot strikes were detected with a threshold of 30 N for impact and toe-off phase during running. Outcome measures for all right foot-steps were identified. For each running speed the last 10 right foot steps were analysed and averaged. A distinction between heelstrike and non-heelstrike landing patterns was made based on the existence of an impact peak Fz1. A heelstrike runner was defined as a runner in which an impact peak could be identified in a minimum of 7 out of 10 steps. Non-heelstrike runners were excluded from analysis to eliminate type of foot strike as a possible confounding variable.

All participants participated in the 9-week running program[19]. Furthermore, all participants received the same general written and oral information on intensity of running and on warming-up and cooling-down. Participants were instructed to walk briskly for 5 minutes as a warm-up and as a cool-down. Participants trained individually 3 times a week on a self-chosen course and surface. As for intensity, participants were advised to run at a comfortable, relaxed pace at which they could converse without losing breath. In training sessions, combinations of running and walking were used.

Self reported information on RRIs and exposure time was collected using an internet based running log. After each training week participants had to fill in their running activities, other sports activities and injuries. If an RRI was the reason for not participating in the running program, information on anatomical site and severity was asked. To point out the anatomical site of an injury, a picture of the lower body was shown after reporting a RRI. In this representation the lower extremity was divided in 42 anatomical parts. By clicking on the anatomical site of the RRI, the same spot was appointed in red. An RRI was defined as any self-reported musculoskeletal complaint of the lower extremity or back causing a restriction of running for at least 1 week. The GRONORUN 2 study showed no effect in reducing RRIs in novice runners. Therefore, data from both groups were pooled, and in the multivariate analysis controlled for group allocation.

Demographic variables and potential kinetic factors associated with RRI were analyzed for differences between male and female participants at baseline using 2-tailed t-tests for normally distributed continuous variables. Differences were considered statistically significant at $p<0.05$. Incidence of RRI was calculated for all participants and for men and women separately as the number of new injuries reported per 100 runners at risk. Exposure time (in hours of running exposure) was calculated from the time a participant started the running program until the runner reported an RRI (injured runners) or until the end of the program (noninjured runners).

Potential kinetic factors associated with RRI were first univariately analyzed to observe the independent link with RRI. Variables independently associated ($p\leq0.25$) with RRI were entered into the Cox regression model. Hazard Ratios (HR) and the corresponding 95% CI were calculated for the kinetic factors associated with RRI. The weight for each risk factor was adjusted for BMI, age, leg length, gender and (intervention) group. The final score was a hazard ratio for risk of RRI compared to participants without RRI identified in the model. All analyses were performed using SPSS version 18.0 (SPSS Inc, Chicago).

Results

Two hundred ten novice runners enrolled in the study, 133 (63.3%) female and 77 (36.7%) male runners. Mean age was 37.2 ± 11.2 years, body mass index (BMI) was 23.9 ± 3.4 $kg \cdot m^{-2}$. Age (35.9 ± 10.7 vs. 39.6 ± 11.4 years) and BMI (23.5 ± 3.5 vs. 24.7 ± 3.1) in female runners were significantly lower compared to male runners. Leg length of female runners was significantly shorter than the male runners. At a running speed of 9 $km \cdot h^{-1}$ female runners showed a significant higher step frequency (2.72 ± 0.17 vs.

2.67 ± 0.16; $p<0.05$), shorter stride length (1.84 ± 0.12 vs. 1.88 ± 0.12; $p<0.01$), shorter time to impact peak, tFz1 (17.5 ± 6.3 vs. 20.8 ± 6.4; $p<0.01$), shorter contact time (224.4 ± 29.8 vs. 233.4 ± 27.4; $p<0.05$) and a higher loading rate (101.3 ± 29.0 vs. 89.7 ± 27.4; $p<0.01$) compared to the male novice runners.

The incidence of an RRI during the 9-week running program was 16.2%. Twenty three female (17.3%) and 11 (14.3%) novice male runners reported an RRI. There was no significant difference in kinetic variables between the incidence of RRIs in female and male runners ($p=0.27$).

The most frequently self reported injured body parts were knees (41.2%), lower legs (23.5%) and ankle or feet (12.1%). There were no significant differences in the location of RRIs between female and male novice runners.

Female and male runners ran on a speed of 9 km·h^{-1}. At this speed no significant differences were observed between the injured group (N = 34) and the noninjured group (N = 176) on all variables for female and male runners (table 1).

Male runners ran on a running speed of 9 and 10 km·h^{-1}. In injured male runners loading rate was significantly higher compared to noninjured male runners at both running speeds (9 km·h^{-}1: 108.6 ± 27.6 vs. 86.58 ± 26.3; $p<0.05$ and 10 km·h^{-1}: 127.0 ± 39.7 vs. 96.7 ± 30.75; $p<0.05$) and contact time in the injured male group was significantly shorter at 9 km·h^{-1} (213.0 ± 39.5 vs. 237.0 ± 26.3; $p<0.05$). The Cox regression analyses showed that only loading rate was univariately associated ($p< .25$) with RRI. After adjusting for BMI, age, leg length, gender and group allocation, no significant association was found between loading rate and RRI (HR 1.01; 95% CI 1.00–1.02).

Table 1 Mean (SD) demographic, spatio-temporal and kinetic variables in injured and noninjured female and male runners. * $p < 0.05$

	Female N = 133		Male N = 77		Total N = 210	
	RRI N = 23	No RRI N = 110	RRI N = 11	No RRI N = 66	RRI N = 34	No RRI N = 176
Age (years)	39.3 (11.8)	35.2 (10.4)	42.6 (15.4)	39.1 (10.6)	40.4 (12.9)	36.6 (10.6)
BMI ($kg{\cdot}m^{-2}$)	24.3 (3.4)	23.3 (3.5)	24.4 (2.9)	24.7 (3.2)	24.3 (3.2)	23.9 (3.4)
Leg length (m)	0.91 (0.06)	0.92 (0.05)	0.98 (0.03)	0.96 (0.05)	0.93 (0.06)	0.93 (0.05)
8 $km{\cdot}h^{-1}$						
Step freq. (Hz)	2.62 (0.19)	2.61 (0.22)				
Stride length (m)	1.69 (0.10)	1.69 (0.10)				
Contact time (ms)	260.7 (44.6)	244.6 (43.8)				
Impact peak (BW)	1.24 (0.18)	1.28 (0.14)				
Time to IP (ms)	18.83 (5.1)	19.80 (6.0)				
Active peak (BW)	1.97 (0.26)	2.00 (0.23)				
Time to AP (ms)	123.0 (19.7)	121.2 (17.0)				
LR ($BW{\cdot}.s^{-1}$)	85.9 (22.2)	88.3 (23.3)				
9 $km{\cdot}h^{-1}$						
Step freq. (Hz)	2.73 (0.18)	2.72 (017)	2.73 (0.16)	2.66 (0.16)	2.73 (0.17)	2.70 (0.17)
Stride length (m)	1.84 (0.12)	1.85 (0.11)	1.83 (0.09)	1.89 (0.12)	1.84 (0.11)	1.86 (0.12)
Contact time (ms)	229.75 (33.2)	223.27 (29.0)	213.0 (39.5)*	236.9 (26.3)*	224.32 (35.6)	228.41 (27.8)
Impact peak (BW)	1.28 (0.19)	1.34 (0.17)	1.32 (0.18)	1.33 (0.15)	1.29 (0.19)	1.34 (0.16)
Time IP (ms)	17.11 (5.16)	17.62 (6.1)	17.49 (7.4)	21.32 (6.2)	17.23 (6.0)	19.01 (6.4)
Active peak (BW)	2.05 (0.28)	2.09 (0.23)	2.07 (0.20)	2.06 (0.23)	2.06 (0.25)	2.09 (0.22)
Time AP (ms)	112.0 (17.3)	112.9 (17.2)	104.3 (25.1)	113.0 (14.0)	109.4 (20.0)	113.2 (16)
LR ($BW{\cdot}s^{-1}$)	97.36 (28.1)	102.1 (29.1)	108.6 (27)*	86.5 (26.3)*	101.0 (28.4)	96.30 (29)
10 $km{\cdot}h^{-1}$						
Step freq. (Hz)			2.81 (0.18)	2.73 (0.19)		
Stride length (m)			1.98 (0.14)	2.04 (0.13)		
Contact time (ms)			204.6 (36.3)	220.2 (25.7)		
Impact peak (BW)			1.40 (0.24)	1.38 (0.17)		
Time to IP (ms)			15.65 (8.77)	19.09 (5.79)		
Active peak (BW)			2.17 (0.20)	2.13 (0.21)		
Time to AP (ms)			98.18 (21.1)	106.1 (15.1)		
LR ($BW{\cdot}s^{-1}$)			127.0 (39)*	96.7 (30.7)*		

Discussion

To our knowledge this is the first published prospective study in novice female and male runners that examined differences in kinetic and spatio-temporal variables between injured and noninjured novice runners. The aim of this study was to determine differences in impact force, active force and loading rate between injured and noninjured runners and the potential contribution to RRIs. Loading rate was significantly higher in injured male runners however, when exposure time was taken into account, the multivariate Cox regression model showed no association between loading rate and other variables to RRI.

The loading rate at 9 and 10 $km \cdot h^{-1}$ in injured male novice runners was significantly higher compared to noninjured male runners. These results should be interpreted cautiously because of the low absolute number of injured male runners. The observed higher loading rate in injured runners was also found in other retrospective studies. In a retrospective cross-sectional study of Hreljac et al.[16], male and female runners who had suffered from an overuse injury, had a higher loading rate and impact peak, when compared to a control group of runners who had never sustained an overuse injury. Milner et al.[20] in a retrospective study, reported that female runners with a history of tibial stress fractures had a higher loading rate and a trend towards higher impact peaks in comparison to an injury free control group. Ferber et al.[15] reported a higher loading rate in a group of male and female runners with stress fractures compared to noninjured runners. In contrast, other studies showed no relation between loading rate and RRIs in male and female runners[21-23] and in military recruits[24].

In male runners impact peak and active peak were not related with RRIs and in the group of female novice runners no differences were found in impact peak, active peak or loading rate between injured and noninjured runners. Several studies reported similar findings and did not find differences in impact peak and active peak or loading rates between injured and noninjured runners[21-23]. Surprisingly, in the prospective study of Bahlsen[17], participants with a higher loading rate and impact peak had significantly fewer running related injuries.

From these new data there seems to be no relationship between impact peak and active peak and the development of RRIs. Loading rate was higher in male injured runners and therefore could be a risk factor for RRIs in male runners. This causality was reported in a review on lower extremity stress fractures by Zadpoor[12]. The importance of this association is that loading rate can be influenced by gait retraining and thereby may reduce the risk of RRIs[18].

Male injured runners showed a significant shorter contact time compared to the noninjured male runners. Contact time is an important determinant for the cost of running and a strong and direct factor influencing leg stiffness[25]. As shown by Morin a 10% decrease in contact time can lead to a 25% increase in leg stiffness[25,26]. So it could be postulated that injured male runners ran with a higher leg stiffness. To our knowledge no research has been done to examine the effect of leg stiffness on the incidence of (running related) injuries.
The incidence of RRIs seemed relatively low in this present study compared to other studies[1-3]. When taking into account the short duration of the program, the incidence rate is comparable with other studies. Buist[1] reported an incidence of 21%. The location and distribution of the RRIs in this study is comparable with other studies in which knee and lower leg were mostly affected[1,5,6].

In this study the incidence of RRIs was the same for female and male runners. Previous studies have indicated that female runners are more likely to develop specific RRIs,[5,20] Different kinematic and kinetic parameters may predispose females to an RRI but the relationship between these gender differences in running are yet to be determined[27]. This study showed differences at baseline measurements between female and male participants. The difference in step frequency, stride length and contact time could be explained by the shorter (leg) length of the female participants. Surprisingly female runners had a significant higher loading rate compared to the male counterparts. Higher loading rates are often implicated as a risk factor for an RRI or stress fracture[15,16,20]. Despite the higher loading rate in this study no difference in incidence of RRIs between female and male runners was seen. Till now little attention has been paid to the biomechanical differences in running between female and male runners and the development of RRIs.

An underlying assumption when using a treadmill for running analysis is that running on a treadmill is similar to overground running. A comparison of the vertical GRFs showed that there were no systematic errors or large differences between both conditions[28]. In another study vertical peak GRF did not significantly differ between overground and treadmill running at 13.7 km·h[29]. When looking at these studies the instrumented treadmill could be used for measuring ground reaction forces that correspond well to normal overground values.

A few limitations of this study should be noted. First, foot structure of the participants was not taken into account. Williams et al. showed that high arch runners have greater overall leg stiffness and a higher vertical loading rate when compared to low arch runners[30]. So foot type could have been a confounding factor in this study.

A second limitation could be the fact that there was no information on speed or intensity of running during the 9-week running program. In this study participants were instructed to run on a comfortable pace during the training program. Training errors (too much, too fast, too soon) are import factors in the development of RRIs. It is possible that a high percentage of injured runners in this study trained at too great of an intensity or duration for their level of fitness. Actual training pace was not objectively measured. Training pace and running kinetics during baseline measurements could have varied and thereby influencing the outcome of this study. A third limitation is the sample size and lack of a clear predetermined power calculation. Only 36 injuries were recorded in the relatively short follow up and this affects the conclusions of this study. A fourth limitation could be the fixed speed at baseline measurements. These speed could have been too easy for some participants whereas for others more difficult. Treadmill speed was fixed because kinetic factors are speed dependent[20.29] and for novice runners it might be difficult to determine their comfortable self-selected running speed. A fifth limitation of the study was the registration of RRIs. Participants registered their musculoskeletal complaints on an internet-based training log. The RRI was not systematically diagnosed by an independent healthcare professional and this may have possibly affected the outcome of this study.

Conclusion

The current study provided knowledge on differences in kinetic factors between injured and noninjured female and male novice runners and its potential contribution to RRIs in a 9-week running program. The participants of this present study were mostly inactive, had no sporting or running experience so caution should be taken to generalize these results to other groups of female or male runners. Male injured runners showed higher loading rates and shorter contact times than noninjured runners. In female runners, however, there were no differences in kinetic or spatio-temporal variables between injured and noninjured runners. Female runners had significantly higher loading rates compared to male runners but no difference in the incidence of RRIs was observed.

In future studies attention should be paid to predetermined power analysis, kinetics, kinematics (especially leg stiffness), foot type, longer follow up and during follow up reliable measurements of exposure in terms of speed, intensity, frequency and duration and medically diagnosis of RRIs are needed to shed more light on the complex aetiology of running related injuries.

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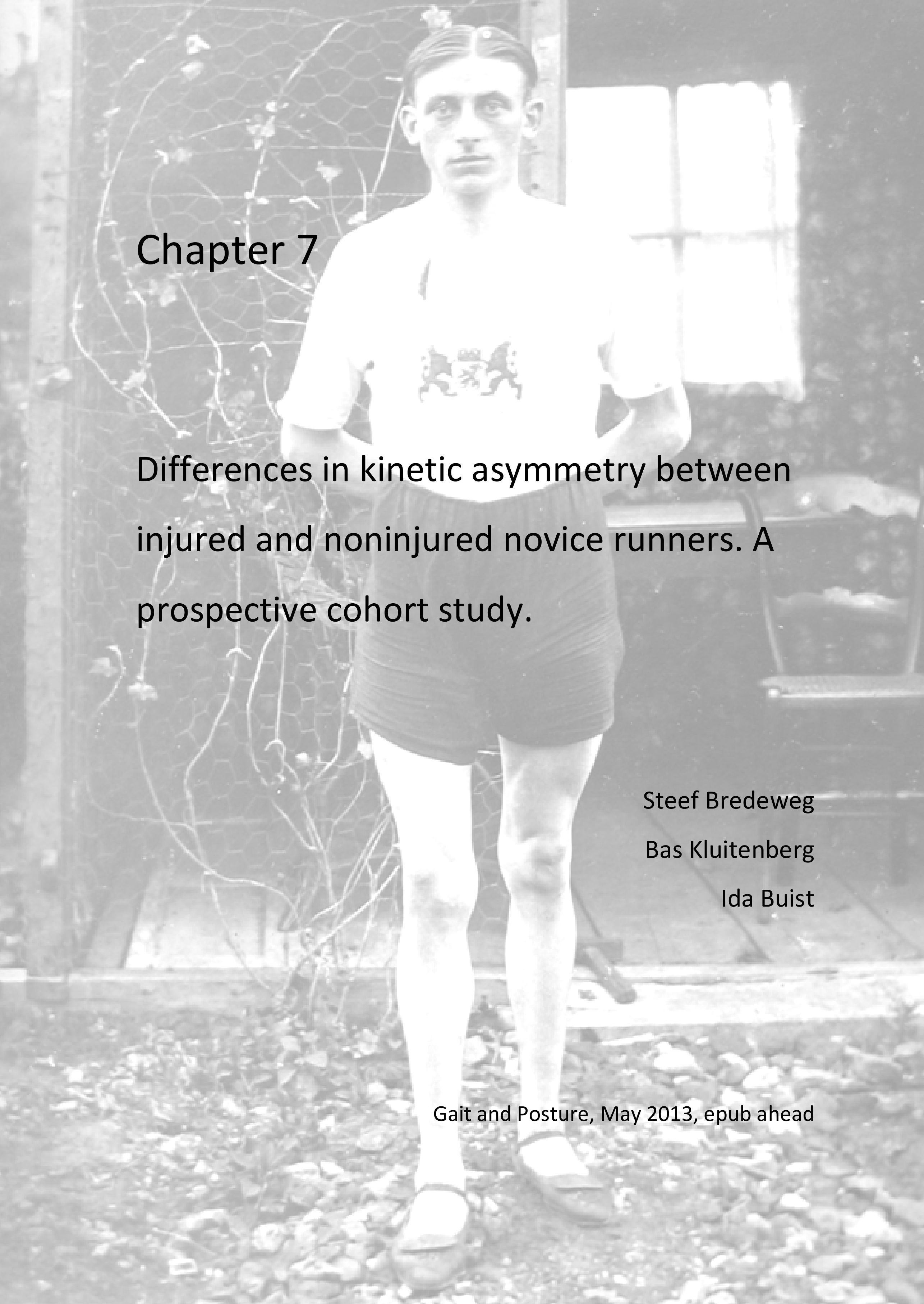

Chapter 7

Differences in kinetic asymmetry between injured and noninjured novice runners. A prospective cohort study.

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Abstract

Purpose: The purpose of this prospective study was to describe natural levels of asymmetry in running, compare levels of asymmetry between injured and noninjured novice runners and compare kinetic variables between the injured and noninjured lower limb within the novice runners with an injury.

Methods: At baseline vertical ground reaction forces and symmetry angles (SA) were assessed with an instrumented treadmill equipped with three force measuring transducers. Female participants ran at 8 and 9 km·h^{-1} and male runners ran at 9 and 10 km·h^{-1}. Primary outcome measure was a running related injury (RRI). Participants were novice female and male recreational runners and were followed during a 9-week running program.

Results: Two hundred ten novice runners enrolled this study, 133 (63.3%) female and 77 (36.7%) male runners. Thirty-four runners reported an RRI. At baseline SA values varied widely for all spatio-temporal and kinetic variables. The inter-individual differences in SA were also high. No significant differences in SA were found between female and male runners running at 9 km·h^{-1}. In injured runners the SA of the impact peak was significantly lower compared to noninjured runners.

Conclusions:

Natural levels of asymmetry in running were high. The SA of impact peak in injured runners was lower compared to noninjured runners and no differences were seen between the injured and noninjured lower limbs.

Introduction

Annually, 19 to 83% of all runners sustain a running-related injury (RRI).[1,2] Notwithstanding the high risk of sustaining an RRI, running is still one of the most popular physical activities. Injuries most common sustained among runners are medial tibial stress syndrome, patellofemoral pain syndrome, iliotibial band syndrome, stress fractures of the tibia, fibula or metatarsals, plantar fasciitis and Achilles tendinopathy.[3] Risk factors that put runners at higher risk for developing an RRI have been studied extensively.[4-6] Risk factors for RRIs can be divided into: training, anatomical and biomechanical factors.[7] Because of the high forces applied to the body with each foot strike, kinetic variables like impact peak,[7] active peak, and loading rate, were often studied in relation to RRIs.[7-11] Results from these often small and retrospective studies were contradictory. In a recent prospective study among 210 novice runners, no differences in kinetic peak values were found between runners who developed an RRI and runners who did not.[12] Therefore, magnitude of the impact and active peak forces might not be directly related to the development of an RRI.

Kinetic asymmetries between the left and right leg will expose one of the lower limbs to more stress than the other.[13,14] Therefore, the musculoskeletal tissue of the leg that is exposed to higher levels of stress might be more susceptible to an overuse injury. Only two studies examined this possible relation between kinetic asymmetry and RRIs.[13,14] Both studies did not find differences in asymmetry between injured and noninjured runners. However, due to the retrospective character of both studies these findings might as well be the result of the injury. It can be argued that asymmetry is reduced as result of the injury, to decrease loading on the injured side. A prospective study can elucidate the possible causative nature of kinetic asymmetry on RRIs.

Studying the possible relation of kinetic asymmetry to RRIs is of importance for several reasons. Firstly runners at risk could be easily identified by measuring kinetic variables of both legs. Secondly, preventive measures such as the use of insoles or shoe modifications could be developed and introduced to reduce asymmetry in kinetic variables causative in the development of RRIs.[15] And thirdly, running technique could be modified in a way to reduce imbalances in load to the lower extremity and thereby decrease the risk on an RRI.[16]

The purpose of this prospective study was three-fold. First, describe natural levels of asymmetry. Second, compare levels of asymmetry between novice runners who sustained an RRI and novice runners who did not sustain an RRI. Third, compare kinetic variables between the injured and noninjured lower limb within the novice runners who sustained an RRI. It was hypothesized that runners who had higher levels of asymmetry in impact peak, active peak and loading rate were more likely to sustain an RRI on the side where loading was highest.

Methods

Novice runners between the 18 and 65 years old were recruited from the GRONORUN 2 study population.[17] The GRONORUN 2 study was a randomized control trial which studied the effect of a preconditioning program on the incidence of RRIs. After baseline measurements and informed consent, participants were randomly assigned to the 4 week preconditioning program group or the control group. After inclusion in the GRONORUN 2 study a random selection of 272 participants was asked to participate in the additional treadmill running test. Before the measurements started, all participants signed written informed consent. An extensive description of the GRONORUN 2 study can be read elsewhere.[16] The study design, procedures, and informed consent procedure were approved by the Medical Ethics Committee of the University Medical Center Groningen, The Netherlands; 2007.217.

Baseline measurements

The treadmill measurements started with a 5 minute walk at 5 km·h^{-1}. After this warming-up, female runners were tested at a running speed of 8 and 9 km·h^{-1} and male runners were tested at a running speed of 9 and 10 km·h^{-1} for one minute. Vertical ground reaction forces (vGRFs) were measured during treadmill running. During the measurements, participants were running on their personal running shoes.

The instrumented treadmill used in this study (Entred, Forcelink, Culemborg, the Netherlands), had a stiff running surface of 1.60m in length and 0.60m in width, and was driven by a 1.8 kW motor. The treadmill was equipped with three force transducers (ACB-500kg, Vishay Revere Transducers, Breda, the Netherlands) which had a sample frequency of 1000Hz and were connected to bridge amplifiers. The signals from the amplifiers were digitized into a 16-bit signal by an AD converter (PCI-6220, National Instruments, Austin, TX, USA) and were connected to a computer. In a recent study the treadmill was validated using a Bertec force platform (0.60m x 0.40m) mounted in the middle of a 17.5m long runway. Intra class correlations were obtained for impact peak (Fz1): 0.71 (95% CI: 0.35-0.89), active peak (Fz2): 0.89 (95% CI: 0.76-0.96), Loading rate (LR): 0.80 (95% CI: 0.57-0.91), time to Fz1: 0.82 (95% CI: 0.56-0.93), time to tF2: 0.94 (95% CI: 0.85-0.97) and contact time (CT): 0.92 (95% CI: 0.82-0.97).

Data analysis

Vertical GRF data from the treadmill were processed using custom programs written in MATLAB R2010a (The MathWorks inc, Natick, MA). A 13-point moving average filter was used to filter the vGRF data that was captured during the treadmill test. Foot strikes were detected with a threshold of 30 N for impact and toe-off phase during running. Outcome measures were identified and averaged for the last 20 (10 left and 10 right) steps for each speed. A distinction between heelstrike and non-heelstrike runners was made based on the existence of an impact peak. A heelstrike runner was defined as a runner in which an impact peak could be identified in 70% of the steps. Non-heelstrike runners were excluded from analysis to eliminate type of foot strike as a possible confounding variable.

The Symmetry Angle (SA) was used to quantify level of symmetry in kinetic outcome measures between the left and the right leg.[18] The Symmetry Angle was calculated with the following equation:

$$SA = (45° - \arctan(X_{left} / X_{right}) / 90° * 100\% \quad (1)$$

The SA is a measure related to the angle formed by the vector of two values (left and right) when plotted in a Cartesian coordinate system. The deviation of this angle from the vector of perfect symmetry (45°) is a measure of asymmetry between the two values. When this deviation is normalized to the maximum deviation of 90°, an SA value of 0% indicates perfect symmetry, while 100% indicates that two values are equal and opposite. SA values were calculated for each of the seven kinetic variables for all female and male runners running at respectively 8 km·h^{-1} and 9 km·h^{-1} or 9 km·h^{-1} and 10 km·h^{-1}. To test for differences in symmetry between the injured and noninjured runners, SA values were calculated at a running speed of 9 km·h^{-1}. For all runners exposure time (in hours of exposure) was calculated from the time a participant started the running program until the runner reported an RRI or until the end of the program.

For comparison of the injured versus the noninjured side in one sided injured runners, a ratio (injured side / noninjured side * 100%) was calculated for each kinetic variable. When ratio values were above 100%, load was higher on the injured side and vice versa.

Percentiles were calculated for symmetry angels of each kinetic variable. Subsequently, plots of relative incidence of RRI against level of asymmetry (lowest 25% of SA values, mid 50% of SA values, or highest 25% SA values of the sample) were made for impact peak, active peak, loading rate and contact time for both male and female runners. Relative incidence of RRI was calculated as number of injuries reported per 100 runners at risk.

Statistical analysis

The kinetic SA values were not normally distributed and data transformation did not result in statistical normality. Therefore, nonparametric tests were used to compare SA values at baseline measurements between different running speeds, gender and between injured and noninjured runners at 9 km·h^{-1}. Pearson's chi-square tests were used to test for significant associations in the relative RRI incidence plotted against level of asymmetry. To test for differences between the injured and noninjured side within the injured runners, paired t-tests were conducted. Differences were considered statistically significant at $p<0.05$.

The symmetry angles of kinetic variables as potential factors associated with RRI were first analyzed to observe the independent link with RRI. Variables independently associated ($p\leq0.25$) with RRI were entered into the Cox regression model. Hazard Ratios (HR) and the corresponding 95% CI were calculated for the SA values associated with RRI. The weight for each risk factor was adjusted for BMI, age, gender, leg length and (intervention) group. The final outcome was a hazard ratio for risk of RRI compared to participants without RRI identified in the model. All analyses were performed using SPSS version 18.0 (SPSS Inc, Chicago).

Results

Two hundred ten novice runners enrolled in the study, 133 (63.3%) female and 77 (36.7%) male runners. Mean age was 37.2 ± 11.2 years, body mass index (BMI) was 23.9 ± 3.4 $kg\cdot m^{-2}$. Age (35.9 ± 10.7 vs. 39.6 ± 11.4 years) and BMI (23.5 ± 3.5 vs. 24.7 ± 3.1) in female runners were significantly lower compared to male runners. Leg length of female runners (0.93 ± 0.06) was significantly shorter than the male runners (0.93 ± 0.05). The incidence of an RRI during the 9-week running program was 16.2%. Twenty three female (17.3%) and 11 (14.3%) novice male runners reported an RRI.

Natural levels of asymmetry

Kinetic variables and corresponding SA values for female running at 8 and 9 $km\cdot h^{-1}$ and male participants running at 9 and 10 $km\cdot h^{-1}$ can be found in respectively table 1 and 2. In female runners SA values for step length were significantly smaller when running at a 9 $km\cdot h^{-1}$ compared to 8 $km\cdot h^{-1}$. For male runners, no significant differences in symmetry were found between both running speeds.

Table 1: Mean (SD) spatio-temporal and kinetic variables of the left and right leg with corresponding symmetry angle (SA) in female runners while running at 8 and 9 km·h^{-1}.

	Female 8 km·h^{-1} (N=133)			Female 9 km·h^{-1} (N=133)		
	Left (SD)	**Right (SD)**	**SA (SD)**	**Left (SD)**	**Right (SD)**	**SA (SD)**
Step Length	0.85 (0.05)	0.85 (0.05)	0.62 (0.66)	0.92 (0.06)	0.92 (0.06)	0.48 (0.40) *
Contact Time	247.1 (43.7)	247.4 (48.7)	1.62 (2.05)	224.3 (28.0)	224.4 (29.7)	1.61 (1.91)
Impact Peak	1.27 (0.16)	1.27 (0.15)	2.43 (2.38)	1.33 (0.16)	1.33 (0.17)	2.53 (2.62)
Time to IP	19.5 (5.5)	19.6 (5.7)	4.68 (3.93)	17.5 (5.7)	17.5 (6.0)	5.31 (4.48)
Active Peak	1.95 (0.23)	2.01 (0.23)	1.94 (1.32)	2.04 (0.22)	2.09 (0.23)	2.08 (1.30)
Time to AP	121.8 (18.0)	121.5 (16.7)	2.23 (3.16)	113.9 (18.1)	112.8 (17.1)	2.18 (2.51)
Loading Rate	89.46 (25.9)	87.96 (23.0)	3.49 (3.17)	100.6 (29.1)	101.3 (29.0)	3.43 (2.81)

* $P < 0.05$

Table 2: Mean (SD) spatio-temporal and kinetic variables of the left and right leg with corresponding symmetry angle (SA) in male runners while running at 9 and 10 km·h^{-1}.

	Male 9km·h^{-1} (N=77)			Male 10km·h^{-1} (N=77)		
	Left (SD)	**Right (SD)**	**SA (SD)**	**Left (SD)**	**Right (SD)**	**SA (SD)**
Step Length	0.94 (0.06)	0.94 (0.06)	0.57 (0.49)	1.02 (0.07)	1.02 (0.06)	0.50 (0.40)
Contact Time	231.7 (29.2)	233.6 (27.4)	1.34 (1.96)	218.5 (30.3)	218.0 (27.8)	1.23 (1.94)
Impact Peak	1.34 (0.16)	1.34 (0.15)	2.75 (2.00)	1.37 (0.17)	1.38 (0.18)	2.56 (2.35)
Time to IP	20.3 (5.9)	20.8 (6.4)	4.80 (3.42)	17.8 (5.6)	18.6 (6.3)	5.30 (4.13)
Active Peak	1.99 (0.21)	2.07 (21.0)	2.71 (1.43)	2.08 (0.23)	2.14 (0.20)	2.80 (2.13)
Time to AP	111.5 (18.9)	112.4 (16.2)	2.13 (2.46)	106.2 (16.7)	106.0 (16.2)	2.14 (2.46)
Loading Rate	92.14 (28.8)	89.73 (27.4)	3.35 (3.19)	104.4 (35.9)	101.0 (33.6)	3.72 (3.81)

* $P < 0.05$

Injured versus noninjured runners

A comparison of injured and noninjured runners with respect to kinetic variables and corresponding SA values can be found in table 3. Injured runners had significant higher SA for contact time and significant lower SA values for impact peak. As shown in figure 1, the relative incidence of RRIs was significantly different for impact force in female runners ($\chi^2(2)=10.67$, $p=0.005$) and for loading rate in male runners ($\chi^2(2)=6.42$, $p=0.04$) for the lower, median and upper quartiles. The Cox-regression analysis showed that after adjusting for BMI, age, gender, leg length and group allocation, no significant relations were found between asymmetry in impact force and RRI (HR 0.84; 95% CI 0.69–1.02; p=0.08) or asymmetry in contact time and RRI (HR 0.98; 95% CI 0.83–1.15; p=0.80).

Table 3: Mean (SD) spatio-temporal and kinetic variables of the left and right leg with corresponding symmetry angle (SA) in injured and noninjured runners at 9 $km{\cdot}h^{-1}$. Differences in SA between injured and noninjured runners were tested with Mann-Whitney tests. * $P < 0.05$

	RRI 9km·h^{-1} (N=34)			**No RRI 9km·h^{-1} (N=176)**			**P-value**
	Left (SD)	**Right (SD)**	**SA (SD)**	**Left (SD)**	**Right (SD)**	**SA (SD)**	
Step Length	0.92 (0.06)	0.92 (0.06)	0.43 (0.3)	0.93 (0.06)	0.93 (0.06)	0.53 (0.4)	0.274
Contact Time	225.1 (35.0)	224.3 (35.7)	1.53 (1.04)	227.4 (27.3)	228.4 (27.8)	1.50 (2.06)	0.042*
Impact Peak	1.28 (0.20)	1.29 (0.18)	1.89 (1.9)	1.34 (0.15)	1.34 (0.16)	2.75 (2.5)	0.021*
Time to IP	17.1 (6.1)	17.2 (5.8)	5.09 (3.6)	18.8 (5.9)	19.0 (6.4)	5.13 (4.2)	0.805
Active Peak	1.98 (0.26)	2.06 (0.25)	2.31 (1.6)	2.03 (0.21)	2.09 (0.22)	2.31 (1.3)	0.824
Time to AP	110.0 (25.1)	109.5 (20.1)	2.98 (4.03)	113.6 (16.8)	113.2 (16.0)	2.00 (2.04)	0.620
Loading Rate	99.92 (30.59)	101.01 (28.4)	3.80 (2.92)	97.06 (29.02)	96.28 (29.01)	3.33 (2.95)	0.392

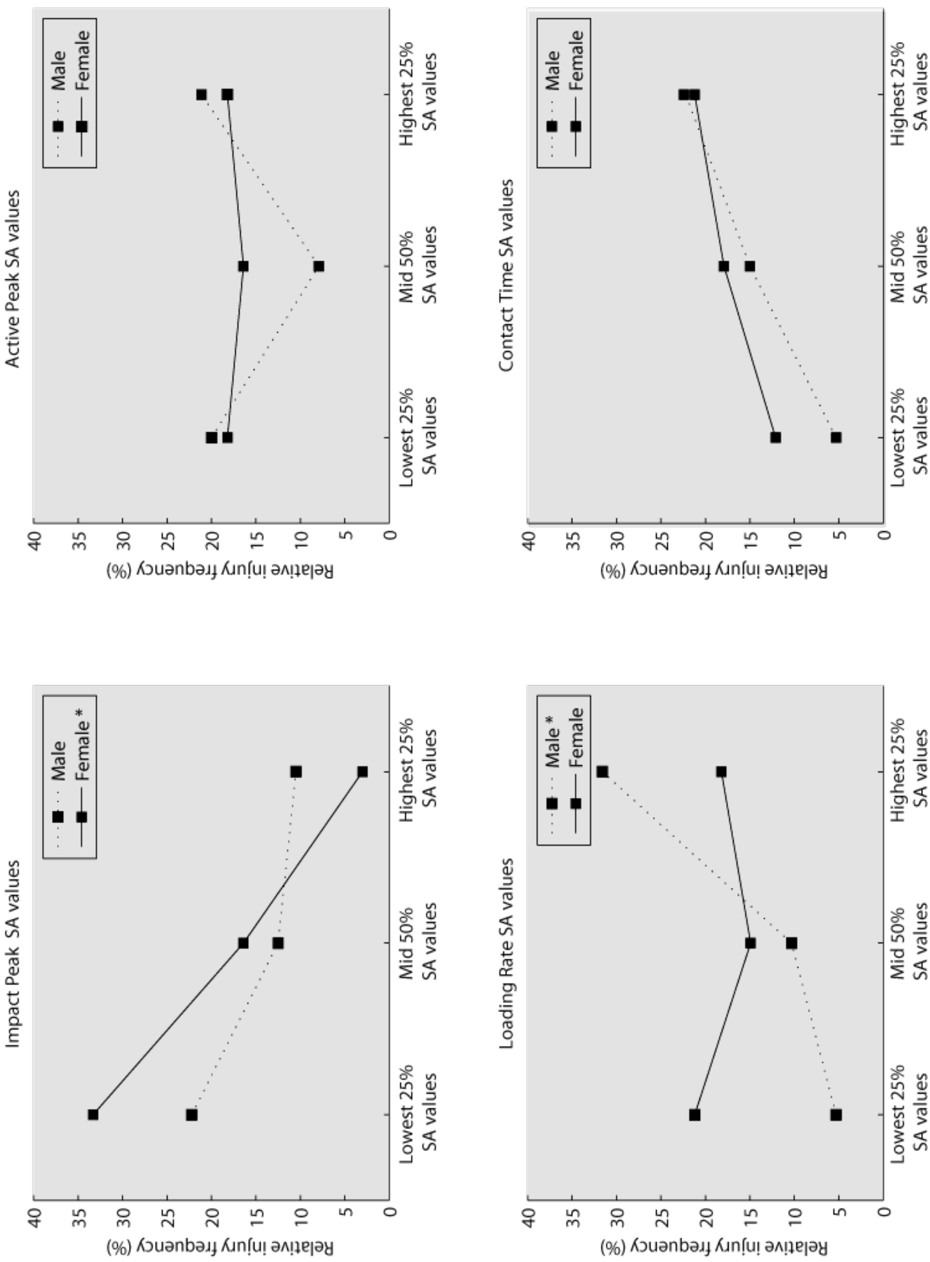

Figure 1. Relative injury frequency and level of asymmetry for impact force, active force, loading rate and contact time. Significant differences are indicated with an *.

Injured versus noninjured side

In table 4, a comparison was made between the injured and the noninjured side within the injured runners. Six injured runners were not taken into account, because injury was not one sided. Within the injured runners, no significant differences existed between the injured and noninjured side.

Table 4: Mean (SD) spatio-temporal and kinetic variables of injured versus noninjured side in the injured runners (N=28) and corresponding ratio (injured / noninjured * 100%).

	Injured side (SD)	Noninjured side (SD)	Ratio (SD)
Step Length	0.91 (0.6)	0.91 (0.6)	100.1 (1.8)
Contact Time	222.5 (0.4)	221.4 (0.4)	100.3 (6.5)
Impact Peak	1.27 (0.19)	1.28 (0.22)	100.2 (8.1)
Time to IP	15.7 (6.3)	16.8 (6.7)	97.6 (28.6)
Active Peak	2.00 (0.27)	2.01 (0.27)	99.8 (8.6)
Time to AP	108.2 (25.3)	108.2 (20.2)	99.6 (15.4)
Loading Rate	102.37 (30.02)	100.88 (28.11)	102.0 (15.5)

Discussion

To our knowledge this is the first published prospective study in novice female and male runners that examined differences in symmetry of kinetic and spatio-temporal variables between injured and noninjured novice runners.

Natural levels of asymmetry

The high variability in asymmetry between different kinetic and spatio-temporal variables and the high inter-individual differences in symmetry which were observed in this study (0.48 - 5.31) were also seen in other studies.[14,19-21] In studies with measurement of both kinematic and kinetic asymmetries, kinetic SA values were more than nine times larger than the SA values of kinematic variables.[20,21] Cavanagh observed that good runners tended to be more asymmetrical than elite runners.[24] Therefore it could be hypothesized that participants of this study, who were novice recreational runners, should show higher SA values because of the unfamiliarity with running. The SA values in the current study however, were not very different from other studies in which experienced or elite runners were analyzed.[14,22,23] This observation was also done by Steinberg[25] in a study comparing beginning and skilled female distance runners. No significant differences were found in ground reaction force variables.

This study examined relative low running speeds. It could be argued that faster speeds produce less variability for selected variables. In walking there seemed to be a speed dependency for ground reaction force variability with greater asymmetries at lower speeds and improved symmetry at higher speeds.[26] Results of the current study, however, indentified no significant differences in asymmetry between 8 and 9 kmh. Other studies showed the same SA values in running at higher speeds from 2,5 ms to absolute sprinting of over 6 ms and no improved symmetry at higher speeds were found.[13,14,19-21]

To our knowledge this is the first study that demonstrated no significant differences in SA values between female and male runners running at 9kmh. Little is known on gender differences in the variability of running. One study showed that hip and knee kinematics and kinetics did not differ between male and female recreational runners but a symmetry index was not calculated.[27]

From these results it can be concluded that variability between sides at different speeds is a functional physiological phenomena and not perse a pathological condition that needs to be restored to symmetry.

Injured versus noninjured runners

Brody, in the land mark publication on running injuries, stated that while a person is running, minor anatomical and biomechanical abnormalities that are of no functional significance in walking can produce injury.[28] In this study however, most variables showed no significantly different SA between the injured and non injured runners. The SA of contact time was higher and the SA of the impact peak was lower in injured runners compared to noninjured runners. In contrast to previous studies in which no significant differences in asymmetry were found between injured and noninjured runners, the results of this study showed that asymmetry in impact peak was lowest in runners who sustained an RRI.[13,14] The relative injury frequency of an RRI is higher in runners with the lower quartile of SA values for impact peak.

When looking at a multivariate level however, the Cox-regression analysis showed that after adjusting for BMI, age, gender, leg length and group allocation, no significant relation was found between asymmetry in impact peak and RRI. Therefore the level of asymmetry in impact peak cannot predict the development of an RRI, although a trend towards this direction was observed.

These findings are opposite to the idea that high levels of asymmetry predispose runners to a higher injury risk as hypothesized in literature.[14,28]

The results depicted in figure 1 also suggested that the relative injury frequency is highest among male runners with high levels of asymmetry in loading rate. It should be noted however, that the number of RRIs in the group of male runners in the upper quartile for the impact peak SA values were small and this difference could probably be a result of the small number of RRIs.

Caution should been taken when interpreting these data. Although some differences were statistically significant they may not be clinically relevant.

Injured versus noninjured side

Even though previous studies reported higher loading on the injured side of the body[13,14], in the current study no differences in loading between the injured and noninjured leg were found. It should be noted that the previous studies used a retrospective study design. Therefore observed differences in loading of the injured and noninjured side may be the result instead of the cause of injury.

Limitations

This prospective study provides new and interesting information on the association of the asymmetry and RRIs, however some limitations should be noted. In this study asymmetry levels of runners were measured between sides of injured and non injured runners and no intra-limb variability was measured. For asymmetry to be significant, the difference observed between limbs should be larger than the difference within limbs.[23] Therefore, it would have been better to include intra-limb variability into the asymmetry analysis.[23] In the current study, the mean of 10 steps was used for calculation of the symmetry angles. Therefore, intra-limb variance would probably have been averaged mostly.

A second limitation could be the fact that there was no information on speed or intensity of running during the 9-week running program. In this study participants were instructed to run on a comfortable pace during the training program. Training errors (too much, too fast, too soon) are import factors in the development of RRIs. It is possible that a high percentage of injured runners in this study trained at too great of an intensity or duration for their level of fitness. A third limitation is the sample size and lack of a clear predetermined power calculation. Only 36 injuries were recorded in the relatively short follow up and this affects the conclusions of this prospective study. A fourth limitation of the study was the registration of RRIs. Participants registered their musculoskeletal complaints on an internet-based training log. The RRI was not systematically diagnosed by an independent healthcare professional and this may have possibly affected the outcome of this study.

Conclusion

The current study showed that natural levels of symmetry at baseline were different per variable and also inter-individual differences were large. No noteworthy differences in symmetry were found between different running speeds or between male and female runners. The hypotheses that injured novice runners had higher levels of asymmetry in impact peak, active peak and loading rate compared to noninjured runners and that loading was higher on the injured side were not supported.

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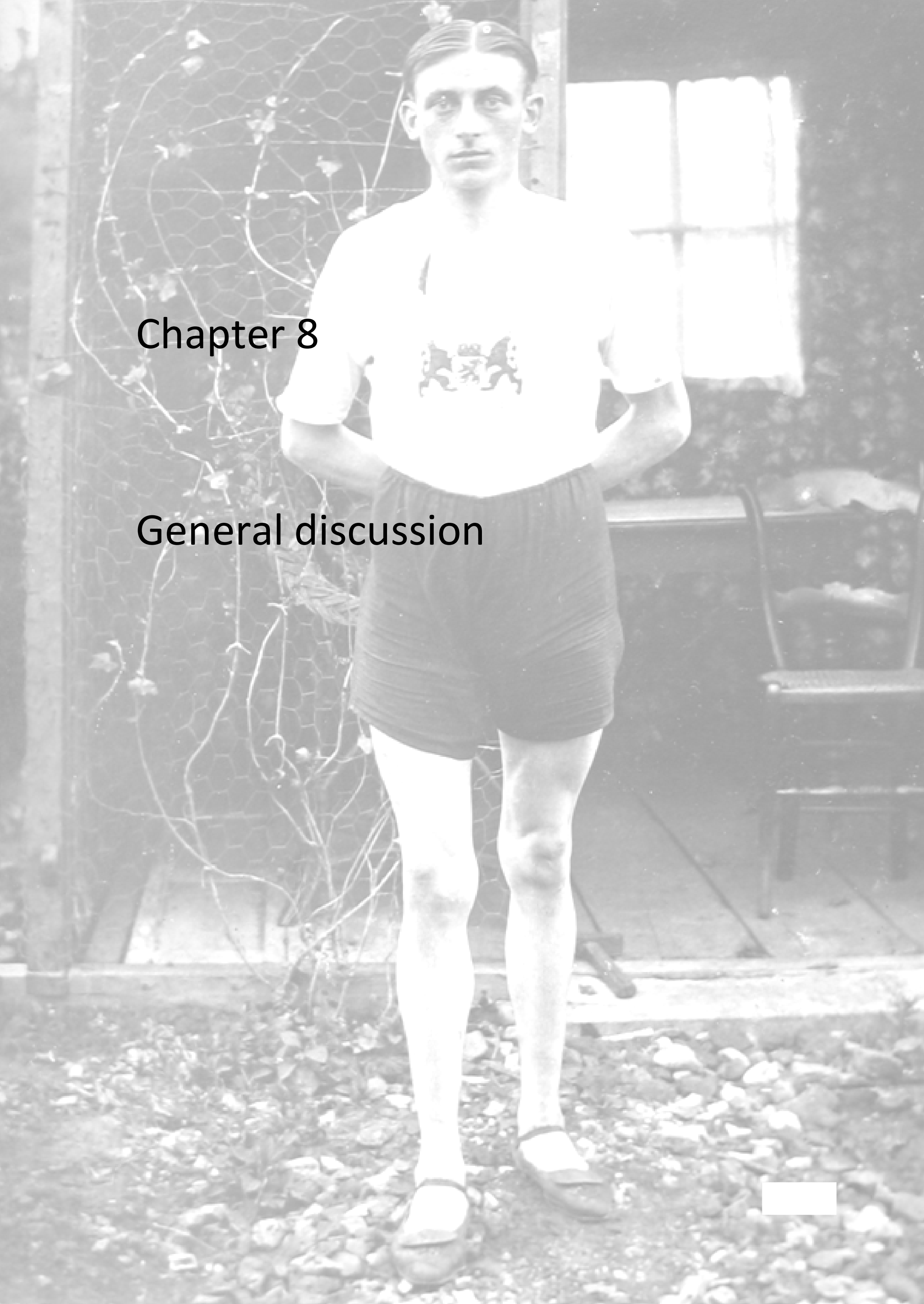
Chapter 8

General discussion



Introduction

Running is a very popular sporting activity that can be done everywhere and by almost everyone. Millions of people are running regularly. It is a healthy activity with positive effects on cardiovascular risk factors, and it gives mental and social benefits. But there is also another side of the medal. Running related injuries (RRIs) are frequent in the running population. From a public health perspective it is important to look for risk factors and interventions to reduce the incidence of RRIs. The aim of this thesis was twofold. First this thesis focused on the effect of a preconditioning program for novice runners to prevent RRIs. The second aim was to look for different kinetic variables in the etiology of RRIs in a group of novice runners.

This general discussion starts out with a summary of the main findings of the research presented in this thesis. Knowledge on risk factors and interventions to prevent RRIs especially in novice runners is scarce and there is still no consensus on the etiology of RRIs (Chapter 2). The GRONORUN 1 study showed that previous sports participation without axial loading was an important risk factor for RRIs in novice compared to novice runners who were engaged in sports with axial loading. From this observation a 4 week preconditioning program in the preparation for a 4 mile run was developed (Chapter 3). The aim of this randomized clinical trial (RCT) was to determine the effect of this preconditioning program on the incidence of RRIs among novice runners. The outcome was that a 4-week preconditioning program with walking and hopping exercises had no influence on the incidence of RRIs in novice runners (Chapter 4).

To study the effect of biomechanical variables in running related research, there is often a trade off between the number of participants included in a study and the type of measurement done in a laboratory. This study showed that the validity of the instrumented treadmill seemed to be suitable for measuring representative vertical ground-reaction forces during running. Another remarkable outcome was that there were no large differences in kinetic variables between treadmill running and overground running (Chapter 5). In a prospective study there were no differences in kinetic or spatiotemporal variables between injured and noninjured female runners.

Injured male runners showed higher loading rates and shorter contact times than noninjured male runners. These results should be interpreted cautiously because of the relatively low number of RRIs in the male group. The difference was significant but is it really clinical relevant (Chapter 6)?

The last issue studied in this thesis was the effect of asymmetry of different variables on the incidence of RRIs. This large prospective study showed that asymmetry in running is high. Asymmetry seemed therefore a natural part of running and not a risk factor for the development of an RRI (Chapter 7).

The results of the research described in this thesis are discussed in a broader perspective. Different steps for an efficient research on preventing running related injuries are presented using the injury sequence model of van Mechelen.[1] The first step in this model establishes the extent of the RRI problem, the second step is looking for the aetiology and mechanisms of RRIs and the third step is the introduction of preventive measures. Where applicable clinical implications and suggestions for further research are being presented.

Running related injuries, risk factors and preventive measures.

In the research for prevention of injuries often the injury sequence model of van Mechelen is used.[1] The first step in this model establishes the extent of the RRI problem, the second step is looking for the aetiology and mechanisms of RRIs and the third step is the introduction of preventive measures.

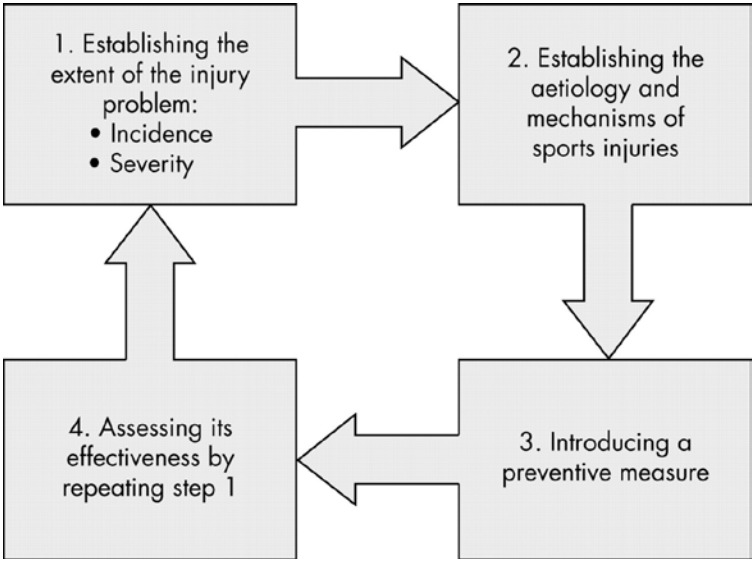


Figure 1: The injury sequence model of van Mechelen. Reprinted with permission

Step 1: Establishing the extent of the problem; Incidence and severity of RRIs.

When looking at step 1 it is known that the incidence of RRIs is high. Incidence rates vary from 20,3% to 84,9% and from 3 to 59 RRIs per 1000 hours of running.[2] In the GRONORUN 2 study described in this thesis the incidence was relatively low with 16%. This low incidence is possibly caused by the short follow up time of 9 weeks. With a longer follow up period, and thereby also a longer training program the incidence could have been higher. In terms of exposure, which is a better figure of expressing injury incidence, there were 30 RRIs per 1000 hours of running. This high outcome is comparable with other running studies. When looking to other injury statistics the incidence of RRIs is very high compared to injuries in other sports.[3]

The exposure of running in the GRONORUN 2 study was measured weekly and the participants filled in their running information. This subjective self reported information on duration and frequency could be misleading and an objective measurement of running exposure is still missing. One study measured exposure using GPS in quantifying training volume in a group of marathon runners.[4] The authors concluded that the GPS seemed a feasible method to obtain information on running volume in a group of runners training in different environments.

Another problem in running related research is the measurement of running intensity. This measurement is possible with the use of heart rate monitoring device or the use of special BORG scales but it is time consuming and often difficult to interpreted.

In different studies and in different populations there is no consensus on the definition of an RRI, and the measurement of the severity of an injury.[2] In the GRONORUN 2 the definition of an RRI was a running related musculoskeletal problem of the lower extremities or back, causing a restriction of running for at least one week, i.e. three consecutive training sessions. Injury severity was not measured in terms of seeking medical attention or time loss of the injury and therefore no conclusions on the severity of RRIs can be drawn. From a methodological point of view it is important to get consensus on the definition of an RRI and on how to measure severity in the population.[5] Future research and consensus on the topic of the definition of an RRI and the measurement of severity are important.

Injuries seen in the GRONORUN 2 studies were overuse injuries of the knee and lower leg. This outcome is comparable to other studies.[2] Since the landmark studies of Brody and Marti in the early 1980s no decrease in the incidence rates of RRIS is seen nowadays.[6,7] In spite of all research, shoe modifications and other knowledge the incidence of RRIs remains high.

Step 2: Establishing the aetiology and mechanism of running related injuries (RRIs).

In running, overuse injuries of the musculoskeletal system generally occur when a structure is exposed to a large number of repetitive forces, each below the acute threshold of a structure, producing a combined fatigue effect over a period of time beyond the capabilities of the specific structure.[8]

Our biological tissues (bone, cartilage, muscles and tendons) are remarkable in that they are capable of going through a remodelling process. When load is applied to the musculoskeletal system micro damage is introduced in the tissue. The remodelling process repairs the damage, and ultimately when there is enough time for this adaptation the musculoskeletal system is getting stronger and more able to withstand the load of running. When the time for adaptation is too short or the volume of running is too high an overuse injury can occur.[9]

As can be seen from the injury model of Hreljac there could be an association between frequency and intensity.[10] When frequency is low the intensity should be high and vice versa. Some people are more injury prone than others, and some people recover better and faster than others after training and the remodelling and adaptation process is probably highly variable.

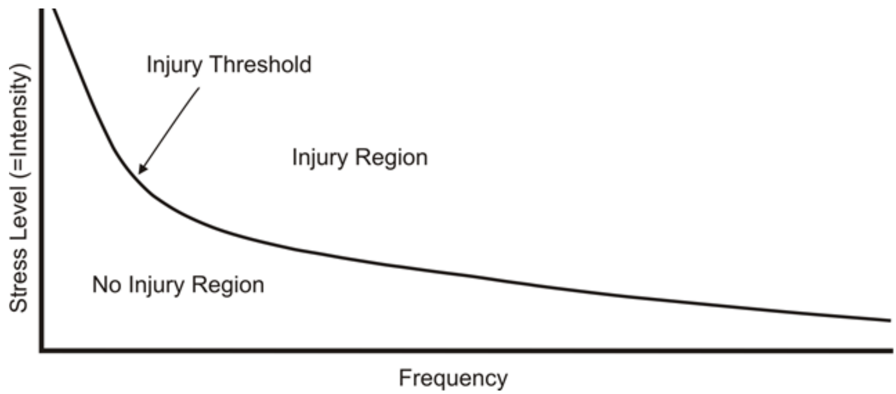


Figure 2: Injury threshold model developed by Hreljec[10]. Reprinted with permission.

Most running injuries are repetitive overuse injuries. The major causes of most overuse running injuries are due to training errors (running too far, too fast, and too often). It is thought that the key factor training volume is for 60-70% associated with the development of an RRI but other risk factors can play a role.[10]

The findings of a very recent study revealed that a sudden increase in weekly training volume may be associated with injury development.[11] The average weekly progression among healthy and injured participants was 22.1 and 31.6%, respectively. These results were not significant but may give an indication that training volume, progression and adaptation time may be important factors in the aetiology of RRIs.

Risk factors can be divided into extrinsic and intrinsic risk factors. Hreljac made a subdivision into three categories; training, anatomical and biomechanical risk factors.[10] The first category is training as an extrinsic risk factor with variables like frequency, intensity, duration, stretching, shoes, running surface, running technique, orthoses, warming up, and cooling down. From the review of van Gent it is known that there is no evidence for the risk factors stretching, running surface, warming up, and cooling down.[2]

In the past few years there have been fierce discussions and debates about shoes, orthoses, running technique and their role in preventing or causing an RRI. The first shoes were introduced over 10,000 years ago. Their function was simply to protect the bottom surface of the foot.[12] When the running boom started in the 1970s running shoes were constructed of flexible material with a thin outersole. In 1972 Nike started with a new brand of shoes with a cushioning in the midsole, this model was called Nike Cortez. The modern running shoe has a shock absorbing midsole, an heel with some elevation and stiff heel counter for optimal shock absorption and motion control. The reasons for these technologies were injury prevention and performance enhancements.

Ryan et al looked for the effect of prescribing motion control shoes to female distance runners.[13] In this randomised controlled trial participants running in motion control shoes obtained more RRIs. In a military study, no significant effect on injury risk was found between recruits receiving motion control, stability or neutral shoes based on the foot's plantar shape compared with recruits who received a stability shoe regardless of plantar shape.[14, 15]

Till now there is no evidence that the modern running shoe technology is preventing RRIs or enhancing running performance. In a study of Richards the evidence of shoe prescription to runners was discussed.[16] The conclusion was clear, there is no evidence that shoe prescription will prevent RRIs in the running population.

In the discussion on running shoes something changed dramatically in 2010. Lieberman published his provoking article in Nature with the title; ''Foot strike patterns and collision forces in habitually barefoot versus shod runners''.[17] In this article he concluded that fore-foot- and mid-foot-strike gaits were probably more common when humans ran barefoot or in minimal shoes, and may protect the feet and lower limbs from some of the impact-related injuries now experienced by a high percentage of runners. This conclusion gave rise to fierce discussions on running blogs and internet running communities. The biomechanical consequences of barefoot running are discussed later in this discussion. Since the Lieberman article there is a rise in so called barefoot running and running with minimalistic shoes. Until now there is no evidence that running barefoot or minimalistic is preventing RRIs.

Another important risk factor as a training variable could be running technique. Normally endurance runners are heel strike runners. In a study of Larson et al looking at foot strike patterns in recreational marathon runners 89% was running with a heel strike, 3% with a mid foot strike and 2% with a forefoot strike.[18]

In a recent retrospective study from Daoud et al foot strike pattern during running is compared to injury rate in 52 competitive cross-country runners on a college team.[19] Surprisingly, heel strike runners RFS runners were 2.5 times more likely to have RRIs compared to mid foot strike runners. Future prospective studies should shed more light on the value and interpretation of these results.

In a personal communication Lieberman quoted; ''How you run is more important than what is on your feet'' and "What is on your feet can affect how you run''.

The second category is anatomical risk factors. These factors are intrinsic risk factors. Examples of this category are foot type, arch height, range of motion (ROM) of the ankle, Q angle, leg length discrepancies, gender, body mass index (BMI), and age.

The most studied risk factor is foot type in the development of RRIs. Two studies in the military population showed no causal relationship between foot type and the development of RRIs.[14, 20] In a recent study Nielsen looked at the foot pronation, using the foot posture index (FPI), and the incidence of RRIs.[21] Over 900 novice runners were followed for one year. All participants were running on neutral running shoes. Foot structure was divided in highly supinated, supinated, neutral, pronated and highly pronated. There was no association between different foot type and RRIs in this large group of novice runners followed for one year. When looking at these data there seems to be robust evidence that foot type is not associated with RRis. But future work on this risk factor has to be done.

Another anatomical risk factor could be asymmetry of the lower extremity. Asymmetry could expose one of the lower limbs to more stress than the other resulting in a lower threshold for the development of a RRI. In this thesis in chapter 7 it was shown that running had a high variability in asymmetry between kinetic but also in spatio-temporal variables. This high variability was seen between runners but also within the runner.

Hamill is a famous running related biomechanical researcher. He introduced the so called coordinative variability hypothesis.[22] In an old Russian study, described in the article of Hamill, it was found that expert pistol shooters had less 'end-point' variability (i.e. the ability to hold the barrel of the pistol steady) than the novice shooters.[22] On the other hand, it was reported that the coordinative variability between the shoulder, elbow and wrist of the expert shooters was greater than the novices. This study shows that the two types of variability are different, have different interpretations, and are related when goal-directed movements are examined. It was reported that greater coordinative variability is the norm for a healthy individual. In the same study Hamill described that individuals with knee pain had lower coordinative variability.[23] This concept was also described in Darwins ''Origin of Species'' in which he talked about the advantages of biological variability.

In literature there were some retrospective data suggesting that a high asymmetry could be a risk factor for tibial stress fracture.[24] In this thesis the asymmetry of injured and non injured runners were studied. Injured runners showed less symmetry in impact peak compared to noninjured runners. No other differences in asymmetry were found between injured and noninjured runners. From these data it can be hypothesized that variability is an important factor in our movement strategies and less variability could be a risk for developing an RRI.

When looking again at the results of this thesis and the hypothesis of Hamill concerning the coordinative variability it seems feasible to do future research on this topic and look for variability of the lower extremity in the running population.[22] In a personal communication with Hamill he stated that preliminary data showed that runners who developed patellofemoral pain had less coordinative variability of the lower extremity compared to runner without patellofemoral pain.

The third risk factor category is biomechanical variables. Examples of this category are kinematics (magnitude and rate of foot pronation, knee, ankle, hip moments) and kinetic (ground reaction forces, impact force, active force, and loading rate).

As discussed earlier barefoot or minimalistic running alters the biomechanics of the lower extremity.[17] In normal shod running with a heel strike pattern a runner has a typical vertical ground reaction force with a so called impact peak. When someone is running barefoot or with minimalistic shoes there is a change in landing strategy. There is no impact peak, and the landing strategy is more directed to a mid foot strike.[17] The impact peak itself is not changing significantly. The stride frequency is higher, and other kinematic changes occur. A recent study of Kulmala showed that forefoot striking produced lower patellofemoral stress and a lower frontal plane knee moment, but a higher ankle plantarflexor moment and a higher achilles tendon loading compared to heel strike running.[25]

When looking at these data it seems that barefoot or minimalistic running is not the holy grail in the prevention of RRIs. When running barefoot the stride frequency is going up so per mile the total load is higher compared to heel strike running. The data from the Kulmala study are possible valuable in the clinical setting.[25] When a runner has a patellofemoral injury he or she can adjust the running technique to a mid foot pattern, or when someone has an achilles tendon disorder he or she can adjust to a more heel strike running pattern.

Another clinical application of this new information can be seen in a recent study by Diebal et al..[26] They showed that forefoot running improved symptoms and disabilities in patients with a chronic compartment syndrome of the lower leg. The positive effect of the modification in running style was still effective after one year.

In this thesis differences in kinetic variables between injured and noninjured runners were studied. No significant differences were found in kinetic or spatio-temporal variables between injured and noninjured female runners. When looking in detail into this study an overlooked variable in running related injury research could possibly be identified. Injured male runners showed a shorter contact time and higher loading rates. So it could be postulated that male injured runners ran with higher leg stiffness. The number of injured male runners was relatively small thus this result must be carefully interpreted.

Runners adjust to ground stiffness and shoe stiffness and try to achieve a constant vertical stiffness by increasing leg stiffness when there is a reduction in surface stiffness or decrease leg stiffness when there is an increase in surface stiffness.[27] When there is a relatively reduced stiffness of the leg this may have implications for soft tissue injury. On the other hand higher relative values of stiffness of the leg may be associated with greater risk of bone injury due to increased loading peaks.[28,29]

So from the results of this thesis and the existing literature an assumption could be made on the effect of lower extremity stiffness and the development of soft tissue or bony RRIs.

Another often forgotten factor is the proximal contribution of structures in the function of the lower extremity. In the past and also in recent years much attention has been paid to the distal coupling or contributions in the development of RRIs of the lower extremity. Excessive or prolonged pronation, tibia rotation, foot alignment, greater Q angles could lead to pathomechanical changes and injuries of the lower extremity.[30]

More recently more research is done looking at the role of the proximal structures in the function of the lower extremity and the role of these structures in the development of sporting injuries. The function of these proximal structures, the lumbopelvic hip complex (core muscles) are essential in their role of controlling movements seen more distally.[31]

The conclusion of the review of Chuter et al is that there is a lack of evidence supporting a cause-effect relationship between distal contributions to lower extremity injury, including RRIs.[30] On the other hand reduced core stability, as a function of proximal structures, is a possible risk factor in the development of overuse injuries in the lower extremity affecting foot and ankle injuries, patello femoral pain syndrome, iliotibial band syndrome and also ACL injury. It is not only a risk factor, it should also be the base of rehabilitation programs after sustaining an injury.[30] Another example of the involvement of the proximal structures is shown in the study by Noehren who showed that female runners who developed patellofemoral pain had different proximal biomechanics compared to healthy female runners.[32]

Step 3: Introducing a preventive measure

The last step in the injury sequence model of van Mechelen is introducing a preventive measure. In the prevention of RRIs a recent Cochrane review was published. In this review interventions for preventing lower limb soft-tissue running injuries were studied.[33] The review included 25 trails. Participants were military recruits (19 trials), runners from the general population (three trials), soccer referees (one trial), and prisoners (two trials). The interventions tested in the included trials fell into four main preventive strategies: exercises, modification of training schedules, use of orthoses, and footwear and socks. The overall conclusion of the authors was that the evidence base for the effectiveness of interventions to reduce soft-tissue injury after intensive running is very weak. More well-designed and reported RCTs are needed that test interventions in recreational and competitive runners.

After the publication two more randomised trials in the prevention of overuse running related injuries were published. The first is the GRONORUN 2 intervention from this thesis (Chapter 4). The aim of this randomized clinical trial (RCT) GRONORUN 2 study was to determine the effect of a preconditioning program on the incidence of RRIs among novice runners. The incidence of RRIs was not statistically different between the preconditioning and control group. The outcome was that a 4-week preconditioning program with walking and hopping exercises had no influence on the incidence of RRIs in novice runners.

Another study looked at the preventive effect of custom made orthoses to prospectively reduce the risk of lower limb injury in military recruits.[34] This study demonstrated a significantly reduced rate of exercise-related lower limb injury across the training period for those wearing the custom made orthoses. In the intervention group using the orthoses there was one injury per 4666 training hours compared to one injury per 1600 in the control group not using custom made orthoses. The absolute risk reduction was 0,44 for men but 0,04 for women. These results look promising but further research in a real running population is necessary.

One of the major challenges in the research for risk factors and preventive measures in running is the methodology of these studies. Often it is hard to find a significant risk factor or effect for an intervention because the sample size is too low. To find an effect of an intervention in the running population sample size normally exceeds 1000 runners with a long follow up. This is often a very costly, time consuming and logistical challenging. In future studies collaboration of different institutes is advisable to work together to find an answer on the etiology of running related injuries.

As mentioned earlier, in preventive medicine it is important to develop interventions based on the understanding of the etiology and mechanisms of injury and the preventive intervention has to be acceptable, practical and adopted by athletes and sport bodies so that the implementation of the intervention can be successful. When looking for an intervention it has to be practical, easy to do and therefore has a good chance for success in terms of compliance, efficacy and effectiveness for the target population.

Clinical applications

This thesis showed that a preconditioning program did not have an effect on the incidence of RRIs in novice runners preparing a 4 mile run. As seen earlier in chapter one other intervention studies in athletes and military population showed a positive effect of precondition program on the incidence of sports and overuse injuries in different populations. From the point of view that every human body can adapt to load is it advisable that novice runners start exercising gradually.

A good advice is start low and go slow. An expert group in the Netherlands developed a training program for novice runners ''Beginnen met hardlopen''. This program can be found on www.sportzorg.nl/beginnenmethardlopen. When someone is not used to exercise or sport they have to start with a four week period with walking sessions. Start with two training walking or running sessions a week. A runner can go the next training session when the runner has no or little complaints like pain or stiffness during the running session or the following morning. Runners can use a visual analogue scale (VAS). The intensity of running has to be a comfortable pace at which a runner could converse without breathlessness. A runner has to learn to listen to the body and not only look at the training program. When the body is given signals of pain or stiffness the runner has to decrease running mileage to prevent an RRI.

As described is this discussion it is not important what kind of shoes a runner is wearing. Lieberman stated that how someone is running is more important than what is on the feet of a runner. This means that a runner can choose a running shoe that is comfortable. When a runner is more frequently running it advisable that a runner buys another but different pair of running shoes.

Kinetic factors like active and impact force and loading rate were no risk factors in the development of RRIs in a group of novice runners. Asymmetry of kinetic and spatio-temporal variables showed no differences between injured and noninjured runners. When looking at risk factors in a broader perspective, as mentioned earlier in this discussion, runners can be advised to train as variable as possible. The runner can try different running surfaces, run with different shoes, with different durations and intensities of training sessions, and the runner can vary with running techniques and other sporting activities with less axial loading. In this way the body gets different stimuli over time and is probably more able to react on these varying loads with a positive adaption of the musculoskeletal system and thereby decreasing the chance for an RRI.

Limitations of the study

Some limitations of this thesis should be mentioned. In the GRONORUN 2 study the incidence of RRIs was relatively low. The sample size calculation was based on a higher incidence of RRIs. Therefore the GRONORUN 2 study could have been underpowered and the outcome of the study should be interpreted carefully. Another issue is the self-registration of the exposure and the fact that there was no information on the intensity of running during the training program.

Another weakness of the GRONORUN 2 study was that no clinical diagnosis of the RRI was made. It was a self reported pain in an anatomical region of the body so a definite diagnosis could not be made. A diagnosis made by a medical doctor or experienced physical therapist is often time consuming and expensive but it is the best option in the methodology of sports injury research.

In the studies looking at biomechanical kinetic risk factors only the aspects of the vertical ground reaction force were taken into account. No information on horizontal ground reaction force or kinematical variables were available. Other shortcomings could be that there was no information on foot type and the fixed speed of the treadmill during baseline measurements. Both variables could have influenced the outcome of the prospective studies.

Future recommendations

In running related injury research more work has to be done to ensure success in preventing running relating injuries. The following recommendations for future running related studies are made:

- Exposure in running should be objectively monitored carefully in terms of speed, intensity and duration.
- The definition and the measurement of the severity of an RRI should be quantified more specifically.
- The running injury should ideally be diagnosed by a medical doctor or physical therapist.
- From a methodological point of view it is important that worldwide research institutes will collaborate on the topic of running and running related injuries.
- Prospective cohort studies focusing on different footstrike patterns and the relationship with the incidence of RRIs should be conducted.
- The coordinative variability hypothesis should be tested in the running population.
- An intervention study comparing a midfoot to a heelstrike running pattern could give important information on the best landing strategy in running and thereby preventing RRIs.
- Studies should be performed looking at the role of stiffness of the lower extremity and the development of RRIs.
- Core stability and the function of proximal musculoskeletal structures should be studied as possible aetiological factors in the development of RRIs.
- Core stability and the function of proximal musculoskeletal should be studied in the treatment of RRIs.

- Studies on the effect of custom made orthoses in the prevention of RRIs in runners should be conducted to look if orthoses are an effective tool to prevent RRIs.

Conclusions

With the new information presented in this thesis the aetiology of RRIs remains still unclear. The primary cause of an RRI is the disbalance between load and time for recovery or positive adaptation of the musculoskeletal system. Most overuse running injuries are due to training errors; this is running too far, too fast, and too often. Since the early 1980s till now the incidence of injuries is still high. Studies looking at risk factors showed that training volume and previous injury is a risk for the development of an injury. Other risk factors showed no significant association with the occurrence of RRIs. This thesis looked also at kinetic and spatio-temporal variables and the effect of asymmetry of different variables and there association with the development of an RRI. No effect of these variables on the incidence of RRIs was found. Therefore it can be stated that the aetiology of RRIs is still unclear and is multifactorial and diverse. Twenty seven randomised controlled studies were conducted to prevent RRIs. Only four studies were conducted in the running population to prevent running related injuries. This thesis looked at the effect of a preconditioning program in novice runners but did not find an effect of this program on the incidence of running related injuries. Even though it may be comparable to the quest for the Holy Grail further studies on modifiable risk factors and prevention of running related injuries need to be performed to better advise the running population in the future.

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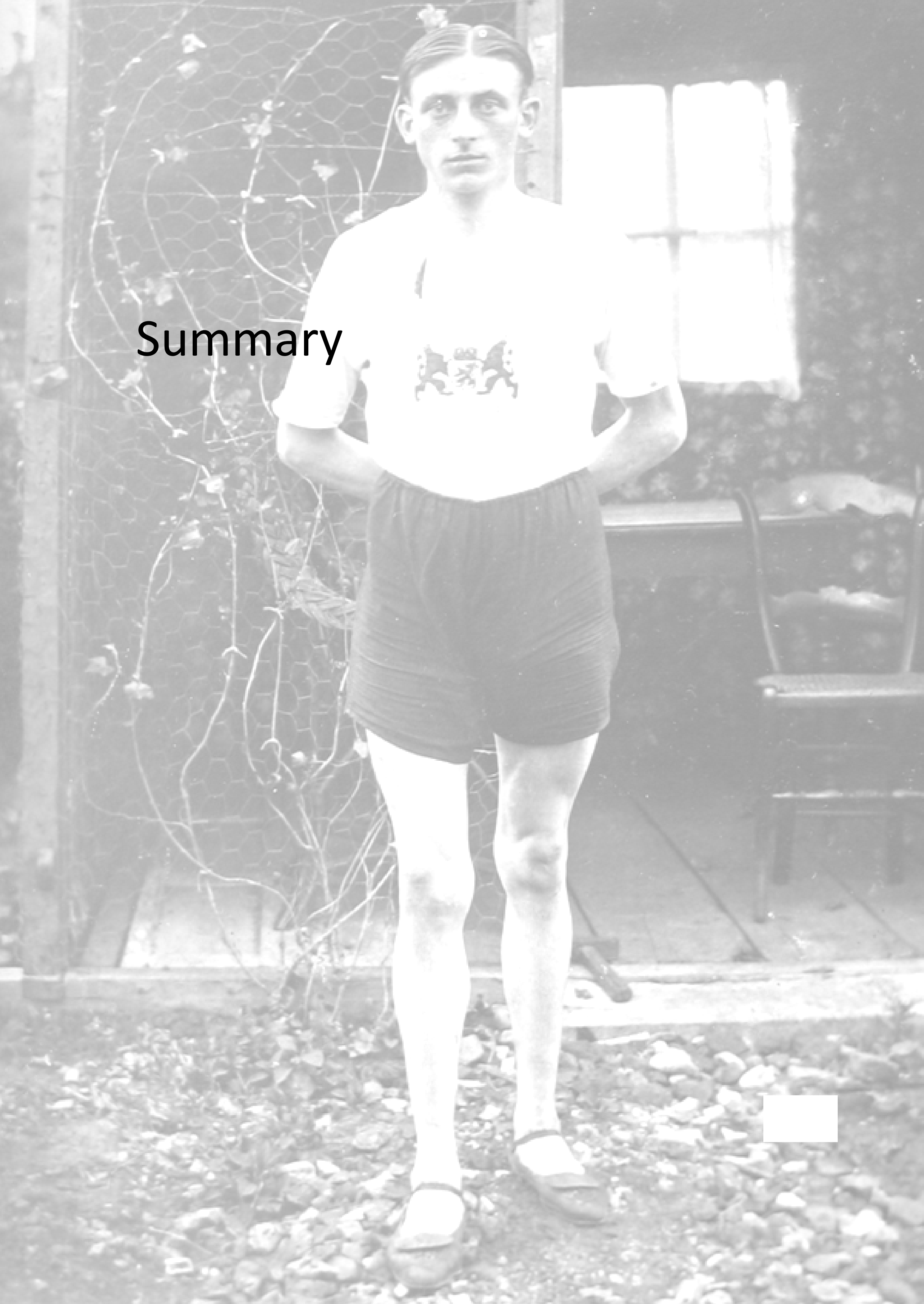
Summary



Running is a very popular sporting activity that can be done everywhere and by almost everyone. Millions of people are running regularly. It is a healthy activity with positive effects on cardiovascular risk factors, and it gives mental and social benefits. But there is also another side of the coin. Running related injuries (RRIs) are frequent in the running population. The primary cause of an RRI is the disbalance between load and time for recovery or positive adaptation of the musculoskeletal system. Most overuse running injuries are due to training errors; this is running too far, too fast, and too often. Since the early 1980s till now the incidence of injuries is still high.
From a public health perspective it is important to look for risk factors and interventions to reduce the incidence of RRIs. The aim of this thesis was twofold. First this thesis focused on the effect of a preconditioning program for novice runners to prevent RRIs. The second aim was to look for different kinetic variables in the etiology of RRIs in a group of novice runners.

This thesis, in *chapter 2*, starts out with an overview of current literature on running and running related research. There are a lot of scientific studies looking at running and RRIs. But high quality studies especially in novice runners are rare and studies looking at risk factors and interventions to prevent RRIs are also scarce. Studies looking at risk factors showed that training volume and previous injury are risk factors for the development of an injury. Other risk factors showed no significant association with the occurrence of RRIs. Till now the etiology of RRIs still remains unclear and no effective interventions in preventing RRIs are found in current literature.

The effect of an intervention in preventing RRIs is presented in *chapter 3*. The GRONORUN 1 study showed that previous sports participation without axial loading (i.e., swimming, cycling, and fitness) was an important risk factor for RRIs in novice runners compared to novice runners who were engaged in sports with axial loading (i.e. soccer, hockey, basketball and volleyball). An intervention was chosen to strengthen the lower extremities to achieve a positive biomechanical adaptation of the

musculoskeletal system before starting a training program for novice runners. The applied external load of this so called preconditioning program will stress the lower extremities and as a result the lower extremities will positively adapt to the applied load which makes it easier to withstand the high demands of running. Other preconditioning programs in athletes and military populations showed a positive effect on the incidence of sports injuries.

In *chapter 3* a 4 week preconditioning program with walking and hopping exercises in the preparation for a 4 mile run is described. The aim of this randomized clinical trial (RCT), the GRONORUN 2 study, was to determine the effect of this preconditioning program on the incidence of RRIs in novice runners. Runners registered their running exposure, other sporting activities and running related injuries in an internet based training log. An RRI was defined as a musculoskeletal complaint of the lower extremities or lower back causing a restriction in running for at least three consecutive training sessions.

Over 400 runners were included and started a 9 week running program. Sixteen percent of all runners got injured and there were 32 injuries per 1000 hours of running. The incidence of RRIs was not statistically different between the preconditioning and the control group. The knee and lower leg were most affected by RRIs. The outcome of this study was that a 4-week preconditioning program with walking and hopping exercises had no influence on the incidence of RRIs in novice runners *(Chapter 4)*.

To study the effect of biomechanical variables in running related research, there is often a trade off between the number of participants included in a study and the type of measurement done in a laboratory. Normally these biomechanical measurements are time consuming, expensive and therefore not suitable for the use in large cohorts. With the development of a custom made instrumented force measuring treadmill it was possible to record sufficient consecutive steps during a stable running pattern in just a few minutes.

In *chapter 5* the validity of this custom made instrumented force measuring treadmill was determined for measuring vertical ground reaction forces during running. Qualitative force curves were quite similar for overground and treadmill running. The high stride-to-stride variance during both overground and treadmill running demonstrated the importance of measuring sufficient steps for representative ground reaction force values. This study showed that the instrumented treadmill seemed to be suitable for measuring representative vertical ground reaction forces during running. Another remarkable outcome was that there were no large differences in kinetic variables between treadmill running and overground running.

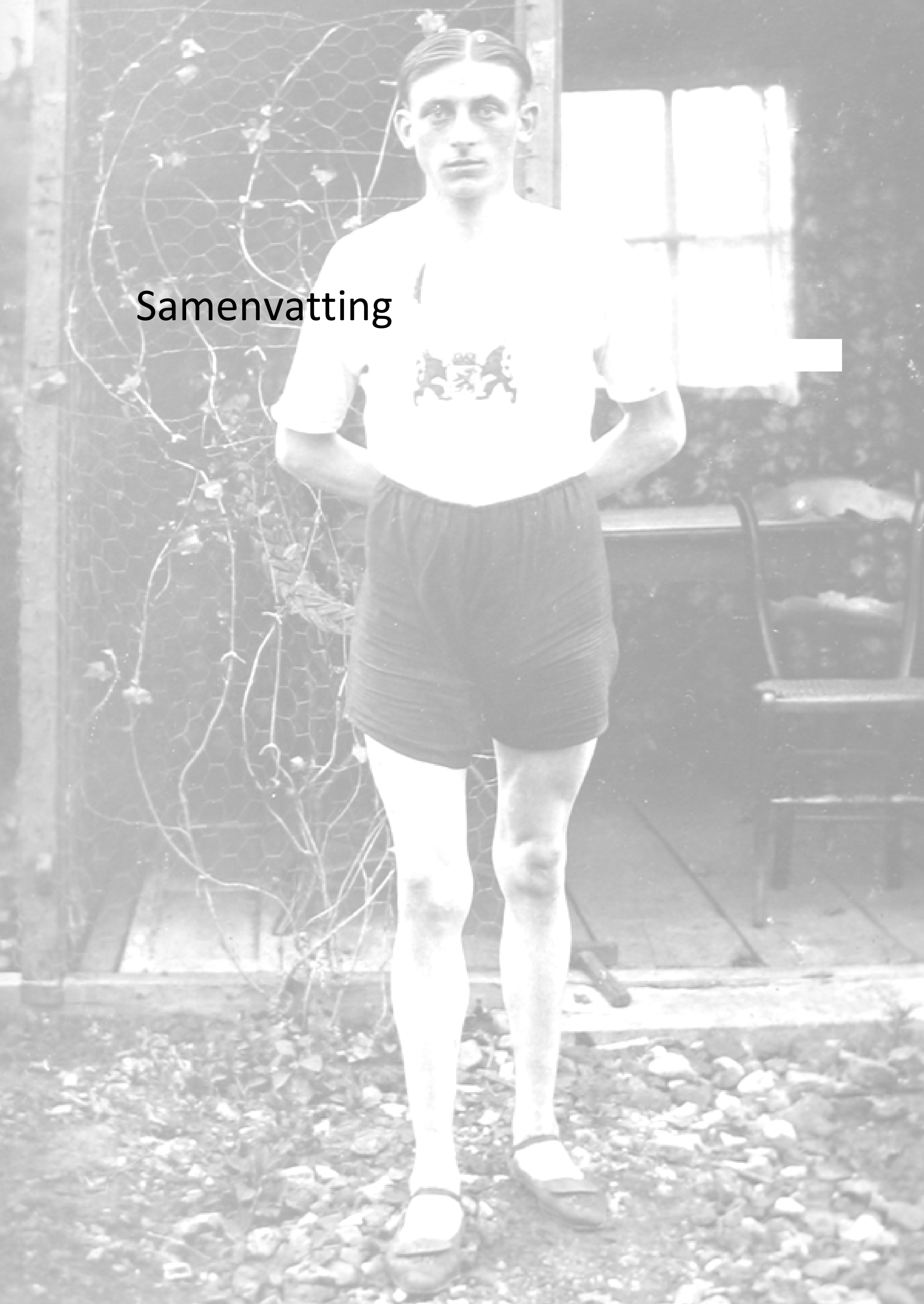
In *chapter 6* different biomechanical variables on the incidence of RRIs in novice runners were studied. This prospective study was conducted with 260 participants of the GRONORUN 2 study. All participants underwent kinetic measurements on the custom made instrumented treadmill. In this study 23 (17.3%) female and 11 (14.3%) male runners got injured. There were no differences in kinetic or spatiotemporal variables between injured and noninjured female runners. Injured male runners showed higher loading rates and shorter contact times than noninjured male runners. These results should be interpreted cautiously because of the relatively low number of RRIs in the male group. The differences were significant but it is questionable if these results are really clinically relevant.

The last issue studied in this thesis was the effect of asymmetry of different variables on the incidence of RRIs and is presented in *chapter 7*. Asymmetry in running is often thought to be an important risk factor for RRIs. An asymmetry between the left and right leg could expose one of the limbs to more stress than the other and therefore the leg that is exposed to higher levels of stress might be more susceptible to an overuse RRI. This large prospective study with 210 participants showed that asymmetry in running was high. The asymmetry of different variables between the right and left leg was high, and this asymmetry was also high between runners. A comparison of injured and noninjured runners with respect to kinetic variables and the symmetry angle values showed no significant differences. A remarkable outcome was that there was no difference in asymmetry between the injured and noninjured leg of the injured runner. Asymmetry seemed therefore a natural part of running and not a risk factor for the development of an RRI.

In the general discussion, *chapter 8*, an overview is given of the results presented in this thesis and these results are discussed in a broader perspective. The injury sequence model of Van Mechelen was used. The first step of this model establishes the extent of the RRI problem. Incidence rates of RRIs vary from 20,3% to 84,9% and from 3 to 59 RRIs per 1000 hours of running. When looking at the etiology and mechanisms of RRIs, the second step in the model, there are only two risk factors identified in the etiology of RRIs. These factors are previous injury and running mileage. Till now no other risk factors are significantly associated with RRIs. The third step is the introduction of preventive measures. A recent review showed only five randomized controlled trials in the running population. None of these studies showed a preventive effect of an intervention on the incidence of RRIs. In future more research should be done looking at running technique ('running form'), foot strike pattern, stiffness of the lower extremity, the so called coordinative variability hypothesis and core stability.

Even though it may be comparable to the quest for the Holy Grail further studies on modifiable risk factors and prevention of running related injuries need to be performed to better advise the running population in the future.

Samenvatting



Hardlopen is een populaire sport die bijna overal en door iedereen gedaan kan worden. Miljoenen mensen lopen regelmatig hard. Het is een gezonde activiteit met positieve effecten op cardiovasculaire risicofactoren en het geeft ook sociaal en mentaal gunstige effecten. Maar er is ook een andere zijde van de medaille. Hardloopblessures komen frequent voor binnen de hardlooppopulatie. De primaire oorzaak van een hardloopblessure is een disbalans tussen belasting en tijd voor herstel en adaptatie van het houdings- en bewegingsapparaat. De meeste overbelastingsblessures in het hardlopen ontstaan ten gevolge van trainingsfouten; te ver, te snel en te vaak. Sinds het begin van de jaren tachtig van de twintigste eeuw tot op heden is de blessure incidentie hoog en tevens ongeveer gelijk gebleven.
Vanuit een publiek gezondheidsperspectief is het belangrijk om te zoeken naar risicofactoren en interventies die zorgen voor een reductie van hardloopblessures. Het doel van dit proefschrift was tweeledig. Ten eerste richtte het zich op het effect van een voorbereidingsprogramma voor beginnende lopers om hardloopblessures te voorkomen. Het tweede doel was het onderzoeken van verschillende kinetische variabelen in de ontstaanswijze van hardloopblessures in een groep beginnende hardlopers.
Dit proefschrift start, in *hoofdstuk 2,* met een overzicht van bestaande literatuur over hardlopen en onderzoek naar hardloopblessures. Er zijn veel wetenschappelijke studies die onderzoek doen naar hardlopen en blessures, maar kwalitatief hoogwaardige studies bij beginnende lopers en studies die onderzoek doen naar risicofactoren en interventies zijn weinig voorhanden. Studies die gekeken hebben naar risicofactoren lieten zien dat het volume van de trainingen en een doorgemaakte blessure een duidelijke relatie hebben met het ontstaan van hardloopblessures. Andere risicofactoren laten geen causaal verband zien met het ontstaan van blessures. Tot op heden is de ontstaanswijze van hardloopblessures onduidelijk en er zijn geen effectieve interventies in het voorkómen van hardloopblessures beschreven in de literatuur.
Het effect van een interventie om hardloopblessures te voorkomen is beschreven in *hoofdstuk 3*. Het GRONORUN 1 onderzoek liet zien dat voorafgaande sport zonder axiale belasting (zwemmen, fietsen en fitness) een belangrijke risicofactor was voor beginnende lopers vergeleken met beginnende lopers die vooraf een sport beoefenden met een axiale belasting (voetbal, hockey, basketbal en volleybal). Een interventie werd gekozen om de onderste ledematen te versterken en een positieve

biomechanische adaptatie van het houdings- en bewegingsapparaat te verkrijgen voorafgaande aan de start voor een training programma voor beginnende hardlopers. De uitwendige belasting van dit voorbereidingsprogramma geeft een prikkel aan de onderste ledematen en deze zullen positief adapteren aan de gevraagde belasting. Op deze manier kunnen de onderste ledematen beter tegen de grote biomechanische belasting van hardlopen. Andere voorbereidingsprogramma's bij sporters en in de militaire populaties laten positieve effecten zien op het voorkomen van blessures.
In *hoofdstuk 3 en 4* wordt een 4 weken durend voorbereidingsprogramma met wandelsessies en hupoefeningen in de voorbereiding voor een 4 Mijl hardloopevenement beschreven. Het doel van deze gerandomiseerde trial, het GRONORUN 2 onderzoek, was het bepalen van het effect van het voorbereidingsprogramma op de incidentie van hardloopblessures bij beginnende hardlopers. Hardlopers registreerden hun hardloopactiviteiten, andere sporten en hardloopblessures in een persoonlijke webbased logboek. Een hardloopblessure werd gedefinieerd als een klacht van het houdings- en bewegingsapparaat van de onderste ledematen of lage rug die een beperking gaf gedurende minimaal drie achtereenvolgende trainingssessies.
Meer dan 400 deelnemers werden geïncludeerd en startten met het 9 weken trainingsprogramma. Zestien procent van alle hardlopers kreeg een blessure en er waren 32 blessures per 1000 uur hardlopen. Er was geen significant verschil in de incidentie van hardloopblessures tussen de voorbereidingsgroep en de controlegroep. De meeste blessures zaten aan de knie en het onderbeen. De uitkomst van deze gerandomiseerde studie was dat een 4 weken durend voorbereidingsprogramma met wandelsessies en hupoefeningen in de voorbereiding voor een 4 Mijl hardloopevenement geen significant effect had op het voorkomen van hardloopblessures bij beginnende hardlopers (*Hoofdstuk 4*).

Bij wetenschappelijk onderzoek naar biomechanische variabelen en hardlopen en blessures is er vaak een trade off tussen het aantal deelnemers aan een onderzoek en de biomechanische metingen. Een uitgebreide biomechanische meting duurt al snel enkel uren en is daardoor duur en niet goed bruikbaar voor onderzoek bij grote cohorten. Met de ontwikkeling van een geïnstrumenteerde loopband met ingebouwde krachtopnemers was het mogelijk om in enkele minuten voldoende achtereenvolgende stappen gedurende een stabiel looppatroon te verkrijgen.

In *hoofdstuk 5* wordt de validiteit van de geïnstrumenteerde loopband met ingebouwde krachtopnemers bepaald voor verticale grond reactiekrachten tijdens het hardlopen. Kwalitatieve krachtcurves waren vergelijkbaar voor lopen op de loopband als voor gewoon hardlopen. Er bleek een hoge variabiliteit te bestaan tussen verschillende stappen van eenzelfde loopsessie gedurende lopen op de loopband en voor gewoon hardlopen. Het is dan ook van belang om voldoende opeenvolgende stappen te analyseren voor een representatieve meting van de verticale grond reactiekrachten. Het onderzoek toonde aan dat de geïnstrumenteerde loopband met ingebouwde krachtopnemers geschikt is om representatieve verticale grond reactiekrachten te meten tijdens hardlopen. Een andere opmerkelijke uitkomst was dat er geen grote kinetische verschillen waren tussen hardlopen op de loopband en gewoon hardlopen.

In *hoofdstuk 6* zijn verschillende biomechanische variabelen onderzocht die voorkomen bij hardloopblessures bij beginnende hardlopers. Dit prospectieve onderzoek is uitgevoerd onder 260 deelnemers aan het GRONORUN 2 onderzoek. Alle deelnemers ondergingen een meting van kinetische variabelen op de geïnstrumenteerde loopband. In dit onderzoek raakten 23 vrouwelijke (17.3%) en 11 mannelijke hardlopers (14.3%) geblesseerd. Er waren geen verschillen in kinetische of spatio-temporele variabelen tussen geblesseerde en niet geblesseerde vrouwelijke hardlopers. Geblesseerde mannelijke hardlopers daarentegen lieten een hogere ‘loading rate’ zien en een kortere contacttijd dan niet geblesseerde mannelijke hardlopers. Deze resultaten moeten met voorzichtigheid geïnterpreteerd worden omdat er relatief weinig hardloopblessures waren in de groep mannelijke groep hardlopers. De verschillen waren wel significant maar het is de vraag of deze resultaten echt klinisch relevant zijn.

Het laatste onderwerp dat onderzocht werd, is het effect van asymmetrie van de verschillende variabelen op het ontstaan van hardloopblessures. De resultaten van dit onderzoek staan beschreven in *hoofdstuk 7*. Asymmetrie wordt in hardlopen vaak gezien als een belangrijke risicofactor voor hardloopblessures. Een asymmetrie tussen linker- en rechterbeen zou er voor kunnen zorgen dat het ene been aan meer belasting blootstaat dan het andere. Daardoor zou het ene been gevoeliger kunnen zijn voor overbelastingsblessures. In deze grote prospectieve studie met 210 deelnemers werd gezien dat er veel asymmetrie is van kinetische en spatio-temporele variabelen bij hardlopen. De asymmetrie van de verschillende kinetische en spatio-temporele variabelen tussen het rechter- en het linkerbeen per individu was hoog, en deze grote asymmetrie was er ook tussen hardlopers onderling. Een vergelijking tussen geblesseerde en niet geblesseerde hardlopers op het gebied van kinetische en spatio-temporele variabelen en de asymmetrische uitkomstwaarden, liet geen significante verschil zien. Een andere opvallende uitkomst was dat er geen verschil was in asymmetrie tussen het geblesseerde en niet geblesseerde been van een hardloper met een blessure. Asymmetrie leek daardoor een natuurlijk onderdeel van het hardlopen en lijkt geen risicofactor voor het ontstaan van een hardloopblessure.

In de algemene discussie, *hoofdstuk 8*, wordt een overzicht weergegeven van de resultaten van dit proefschrift en daar worden de resultaten in een breder perspectief besproken. Het 'injury sequence model' van Van Mechelen werd hiervoor gebruikt als uitgangspunt. De eerste stap van dit model laat het vóórkomen van hardloopblessures in verschillende populaties zien. De incidentie van hardloopblessures ligt tussen de 20,3% en 84,9% en per 1000 uur hardlopen komen er tussen de 3 en 59 hardloopblessures voor. Als er gekeken wordt naar de etiologie van hardloopblessures, de tweede stap in het model, dan worden er slechts twee risicofactoren gevonden die een causaal verband hebben met het ontstaan blessures. Deze risicofactoren zijn het volume van de trainingen en een doorgemaakte blessure. Tot nu toe zijn er geen andere risicofactoren geassocieerd met hardloopblessures. De derde stap in het model is de introductie van preventieve maatregelen. Een recente review liet zien dat er slechts vijf gerandomiseerde studies zijn in de hardlooppopulatie. Geen van deze studies liet zien dat er een preventief effect uitging van interventie op het voorkomen van hardloopblessures. In de toekomst moet er meer onderzoek gedaan worden naar de techniek van hardlopen, de landing en voetafwikkeling, de stijfheid van de onderste extremiteit, de zogenaamde coördinatieve variabiliteits hypothese en de rompstabiliteit.

Hoewel het misschien te vergelijken is met de zoektocht naar de Heilige Graal, is er meer onderzoek nodig naar modificeerbare risicofactoren en het voorkómen van hardloopblessures om hardlopers in de toekomst beter te kunnen adviseren.

Dankwoord

Het voltooien van dit proefschrift is mij niet echt zwaar gevallen. Het meeste heb ik opgezien tegen het schrijven van het dankwoord. Volgens mij kun je dit nooit goed doen. De een krijgt te veel eer, de ander te weinig en belangrijke mensen worden vergeten. Een proefschrift maak je nooit alleen. Er zijn heel veel mensen die bijgedragen hebben aan het ontstaan van het idee, hebben meegedacht om weer stapjes verder te komen en die hebben geholpen om het te voltooien. En er zijn ook veel mensen die toeschouwer zijn geweest van het proces en die hun interesse hebben getoond en meegeleefd hebben. Ik hoop dat iedereen die ik vergeet of tekort doe zelf weet hoe belangrijk hij of zij geweest is bij het tot stand komen van dit proefschrift.

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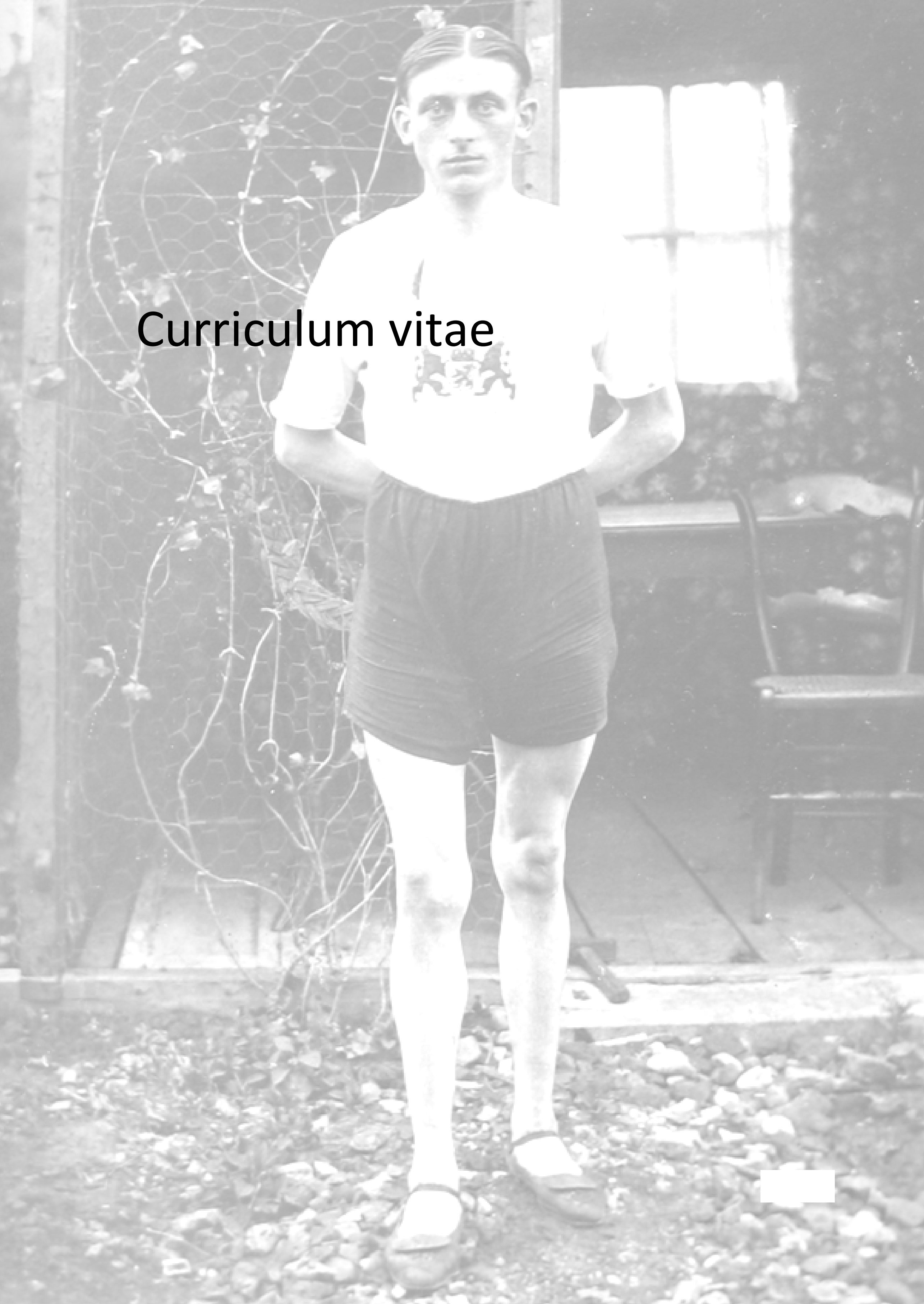
De jonge honden die later het specialisme nog verder moeten gaan brengen. Veel karaktereigenschappen moeten jullie niet van mij over nemen maar probeer toch maar net zo als ik te promoveren. Het is best leuk, je wordt er geen slechter mens van en je helpt het specialisme sportgeneeskunde er mee.

Lieve Margo en Daan,
Ik hoop en ik denk dat jullie niet al te veel last van mij hebben gehad dat ik wat extra uurtjes heb besteed aan dit boekje. In het weekend kon ik soms even geen ontbijt voor jullie maken en soms was ik in gedachten verzonken zonder dat ik aandacht voor jullie had. Het blijft lastig om uit te leggen waarom iemand promoveert. Ik zie promoveren als de kroon op het werk van iets wat je doet, waar je passie ligt en waar je het onderste uit de kan wilt halen.

Lieve Hilde, je hebt me altijd de vrijheid gegeven om alles te mogen doen. Tijdens mijn opleiding tot sportarts in Zwolle en de begeleiding van de Nederlandse volleybal heren was ik meer weg was dan thuis. Dit was voor jou nooit een probleem en dat is daarna nooit veranderd. Je steunde me altijd, niets was teveel, jij regelde het wel en dat gaf mij de kans en het vertrouwen om te worden wie ik ben als sportarts en als mens. In mijn promotietraject was je altijd belangstellend, geïnteresseerd en stond je altijd voor mij klaar met raad en daad. Heerlijk om zo'n mooie vrouw te hebben en (van) te houden! Ik kijk met verlangen naar de toekomst om zo met je door te gaan.

Curriculum vitae



Steef Bredeweg werd geboren op 11 oktober 1964 in Harderwijk. Na de middelbare school in Elburg is hij in 1984 Geneeskunde gaan studeren aan de Rijksuniversiteit Groningen (RUG). Tijdens zijn studie speelde hij 13 jaar volleybal bij GSVV Donitas. Na het behalen van het artsexamen was hij twee jaar dienstplichtig arts op de Johan Willem Friso kazerne in Assen. In zijn diensttijd speelde hij twee wereldkampioenschappen met het Nederlands Militair Volleybal team. Zijn opleiding tot sportarts heeft hij genoten in ziekenhuis De Weezenlanden en het Sophia Ziekenhuis in Zwolle. Op 1 januari 1999 werd hij geregistreerd als sportarts.

Van 1994 tot 1997 was hij de arts van het Nederlands Heren Volleybalteam, waarmee hij in 1996 goud behaalde tijdens de Olympische Spelen van Atlanta. In 1999 werd hij aangesteld als sportarts bij de nieuw opgerichte polikliniek Sportgeneeskunde van het Universitair Medisch Centrum Groningen (voorheen Academisch Ziekenhuis Groningen). Tot op heden is hij nog steeds werkzaam bij het Sportmedisch Centrum (SMC) van het UMCG, tegenwoordig als chef de clinique. Van 2003 tot 2005 is hij clubarts geweest bij de BVO FC Groningen.

Hij is sinds 2011 voorzitter van het concilium Sportgeneeskunde van de Vereniging voor Sportgeneeskunde (VSG), hoofdopleider sportgeneeskunde in de regio Groningen en mede auteur van het opleidingsplan Sportgeneeskunde en het Beroepsprofiel Sportgeneeskunde.

De afgelopen jaren heeft hij zich sterk gemaakt voor de erkenning van Sportgeneeskunde als specialisme en zat hiervoor in de Taskforce erkenning van de VSG en in de commissie Sportgeneeskunde van het College Geneeskundig Specialisme (CGS) die een positief advies voor erkenning bij de minister van VWS hebben neergelegd.

Qua onderzoek houdt hij zich bezig met hardlopen, hardloopblessures en technologische ontwikkelingen in de hardloopsport.

De hoogtepunten van zijn carrière waren het in functie zijn bij het sporthoogtepunt van de 20^{ste} eeuw, de gouden medaille van de Nederlands volleybal heren op de Olympische Spelen van Atlanta, het NOS journaal dat opende met het item 'Het grootste hardlooponderzoek ter wereld' en daarmee doelde op de GRONORUN studie, de aandacht die de New York Times besteedde aan het hardlooponderzoek van het SMC, de Medische Publieksacademie (MPA) lezing in het UMCG over sportblessures, de plenaire lezing op het landelijke congres van het Nederlands Huisartsen Genootschap (NHG) in een bomvol Martiniplaza in Groningen, en de uitnodigingen om lezingen te geven aan de Universiteit van Shanghai en aan het befaamde Aspetar Sports Medicine Instituut in Qatar.

Publicaties

Onderwijsactiviteiten

Opleidingsactiviteiten

Overige activiteiten

Internationale Publicaties

Sobhani S, van den Heuvel E, **Bredeweg SW**, Kluitenberg B, Postema K, Hijmans JM, Dekker R. Effect of rocker shoes on plantar pressure pattern in healthy female runners. Gait and Posture 2013.

Sobhani S, **Bredeweg SW**, Dekker R, Kluitenberg B, van den Heuvel E, Hijmans J, Postema K. Rocker shoe, minimalist shoe, and standard running shoe: A comparison of running economy. J Sci Med Sport 2013.

Bredeweg SW, Kluitenberg B, Bessem B, Buist I. Differences in kinetic asymmetry between injured and noninjured novice runners. A prospective cohort study. Gait and Posture 2013; 38: 847-852.

Bredeweg SW, Kluitenberg B, Bessem B, Buist I. Comparison of vertical ground reaction forces during overground and treadmill running. A validation study. BMC Musculoskelet Disord. 2012.

Bredeweg SW, Kluitenberg B, Bessem B, Buist I. Differences in kinetic variables between injured and noninjured novice runners: A prospective cohort study. J Sci Med Sport. 2013; 16:205-210.

Bredeweg SW, Zijlstra S, Bessem B, Buist I. The effectiveness of a preconditioning programme on preventing running-related injuries in novice runners: a randomised controlled trial. Br J Sports Med. 2012; 46:865-870.

Zwerver J, **Bredeweg SW**, van den Akker-Scheek I. Prevalence of Jumper's knee among nonelite athletes from different sports: a cross-sectional survey. Am J Sports Med. 2011; 39:1984-1988.

Bredeweg SW, I Buist. Running and injuries. A practical approach. Huisarts en Wetenschap 2010; 53: 632-635.

Bredeweg SW, Zijlstra S, Buist I. The GRONORUN 2 study: effectiveness of a preconditioning program on preventing running related injuries in novice runners. The design of a randomized controlled trial. BMC Musculoskelet Disord. 2010; 11:196.

Buist I, **Bredeweg SW**, Lemmink KA, van Mechelen W, Diercks RL. Predictors of running-related injuries in novice runners enrolled in a systematic training program: a prospective cohort study. Am J Sports Med. 2010; 38:273-80.

Buist I, **Bredeweg SW**, Bessem B, van Mechelen W, Lemmink KA, Diercks RL. Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. Br J Sports Med. 2010; 44:598-604.

Bisseling RW, Hof AL, **Bredeweg SW**, Zwerver J, Mulder T.Are the take-off and landing phase dynamics of the volleyball spike jump related to patellar tendinopathy? Br J Sports Med. 2008; 42:483-9.

Buist I, **Bredeweg SW**, van Mechelen W, Lemmink KA, Pepping GJ, Diercks RL. No effect of a graded training program on the number of running-related injuries in novice runners: a randomized controlled trial. Am J Sports Med. 2008; 36:33-9.

Bredeweg SW, Takens LH, Nieuwland W. Periodical cardiovascular screening is mandatory for elite athletes. Neth Heart J. 2007; 15:224-5.

Buist I, **Bredeweg SW**, Lemmink KA, Pepping GJ, Zwerver J, van Mechelen W, Diercks RL. The GRONORUN study: is a graded training program for novice runners effective in preventing running related injuries? Design of a Randomized Controlled Trial. BMC Musculoskelet Disord. 2007; 8:24.

Zwerver J, **Bredeweg SW**, Hof AL. Biomechanical analysis of the single-leg decline squat. Br J Sports Med. 2007;41:264-8.

Bisseling RW, Hof AL, **Bredeweg SW**, Zwerver J, Mulder T. Relationship between landing strategy and patellar tendinopathy in volleyball. Br J Sports Med. 2007; 41.

Reviewer van:

British Journal of Sports Medicine.
Journal of Science, Medicine and Sport.
Sports Medicine.
Nederlands Tijdschrift voor Geneeskunde.
Sport en Geneeskunde.

Internationale presentaties en lezingen.

2013

The science of running and running related injuries. Invited honorary lecture, Aspetar Sports Medicine Hospital, Qatar.
Running related injuries : A medical perspective. Running conference, Aspetar, Qatar.
How to treat the injured runner? A practical approach. Running conference, Aspetar, Qatar.
Return to sport after a running related injury. Workshop, Running conference, Aspetar, Qatar.
The runner with an achilles tendon problem. Workshop, Running conference, Aspetar, Qatar.

2011

Biomechanical risk factors for running related injuries in novice female runners: A prospective cohort study. Biomechanics conference, Humboldt University, Berlin.
Insertional achilles tendinopathy. Invited lecture, Fudan University Shanghai, Shanghai.
Running and running related injuries. Invited lecture, Fudan University Shanghai, Shanghai.
No relationship between running related injuries and kinetic variables. IOC World Conference, Monaco.

2007

Does a modified training program prevent running injuries? First results of a RCT. FIMS Scientific meeting. Beijing.

Nationale lezingen.

2013

Hardlopen en blessures. Loopgroep Drentsche Aa. Groningen.
Kenniscentrum Feet for life; Hardlopen. B&W Borger-Odoorn.
Meerwaarde Sportgeneeskunde in de gezondheidszorg. Menzis lezing, UMCG Groningen.
Sportletsels en gevolgen. Congres traumarevalidatie VRA UMCG.
Hardlopen is cool. KidsInZicht. UMCG Groningen.

2012

Hardlopen en blessures. Boerhaave lezing. LUMC Leiden.
Voetbal en gezondheid. KNVB, Groningen.
De hardloopschoen. VRA congres Groningen.
Pijn in de voet bij hardlopen. Minisymposium huisartsen, Berenloop, Terschelling.

Hamstringblessures. Minisymposium huisartsen, Berenloop, Terschelling.
Wetenschappelijk kennis hardlopen anno 2012. Minisymposium huisartsen, Berenloop, Terschelling.
Masterclass Berenloop Terschelling: Hardlopen en blessures. Kerkje van Terschelling.
Het mediaal tibiaal stress syndroom: Een overzicht. Minisymposium Utrecht.

2011
De inspanningstest. Refereerlunch Beatrixoord, Haren.
Hardloopblessures en behandeling. Minisymposium Bethesda, Hoogeveen
Vocht en voeding bij hardlopen. Minisymposium huisartsen, Berenloop, Terschelling.
Pijn in de onderste extremiteit bij hardlopen. Minisymposium huisartsen, Berenloop, Terschelling.
Return to running na een blessure. Minisymposium huisartsen, Berenloop, Terschelling.
Erkenning Sportgeneeskunde. VSG, Bilthoven.

2010
Sportblessures. Medische Publieksacademie (MPA) UMCG Groningen.
Sportletsel en gevolgen. VRA congres Groningen UMCG.
Sportblessures in de huisartsen praktijk: Plenaire lezing op het Nationale NHG congres te Groningen.

2009
De sportschoen. Symposium de orthopedische schoen VRA. Groningen.
Hardlopen en blessures. Assen.
Sportgeneeskunde in de kliniek. AIOS orthopedie.
Athletic footwear; the running shoe. IVO World Congress, The Hague.

2008
Hoe beginnen met hardlopen. Preclinics 4 Mijl. Groningen.
Warmte en vocht bij inspanning. Clinic 4 Mijl Groningen.
Preventie van sportblessures. Topsport coachplatform. Groningen.
Sportmedische problemen in de huisartsen praktijk. Vakgroep huisartsngeneeskunde RUG Groningen .

2007
Sportblessures in de huisartsenpraktijk. Nascholing Drentse huisartsen. Assen.
Preventie van hardloopblessures. MIC Congres VU Amsterdam.
Sportmedische problemen in de huisartsenpraktijk. Nascholing Drentse huisartsen. Assen.
Keuringen, zin of onzin. Nascholing Drentse huisartsen. Assen.
Hardlopen en blessures. Bijscholing hardlooptrainers KNAU, Groningen
Hardlopen blessures. De Rietplasloop, Emmen.
Heupblessures in de sport. Refereeravond revalidatiegeneeskunde UMCG Groningen.

Sport, bewegen en gezondheid. Lezing voor B&W Marum.
Casuïstiek in de sportgeneeskunde: Huisartsgeneeskunde RUG Groningen.
Ketenzorg van de sportgeneeskunde in UMCG. Bezoek VWS aan UCG, Groningen.

2006
Sportletsels in de huisartsen praktijk. HAGRO Appingedam.
Sportgeneeskunde. Panacea geneeskunde symposium, Groningen.
''Hartlopen''; de zin en onzin van drinken tijdens hardlopen. Huisartsen refereeravond Wenckebach, UMCG, Groningen.
Sportschoeisel. De orthopedische schoen. Revalidatiegeneeskunde symposium.
Sportgeneeskunde. Refereeravond cardiologie en sport. Euroborg, Groningen.
Zin en onzin van de Lausanne screening. KNVB, Groningen.
Overtraining voor trainers. Trainers Olympisch Steunpunt, Groningen.

2005
Sporten en bewegen, Sportcafe Huis voor de Sport, Groningen.
Wat is Sportgeneeskunde? Fysiotherapiesymposium Groningen.
Waarde Sportgeneeskunde?! Debat Johan Derksen, Groningen.
Sport en schoenen Revalidatie Symposium. Groningen.
Sportletsels onder de knie. Knie in beweging; Paterswolde congres, Paterswolde.
Academische Sportgeneeskunde. Openingslezing SMI Leiderdorp.
Enkelblessurepreventie en volleybal. NEVOBO Groningen
De opzet van GRONORUN 1. VSG wetenschappelijk jaarcongres VSG congres

2004
Sport, bewegen en gezondheid. College B&W Hoogezand
Sport en bewegen, de Nacht van Groningen. Gasunie, Groningen.
Hoe gezond is topsport. Symposium Bewegingswetenschappen RUG Groningen.
Knieletsels in de sport. Symposium Revalidatiegeneeskunde; brandwonden en ongevalletsels. Haren.
Hardlopen en Gezondheid. Lezing PV UMCG
Blessurepreventie en de 4 mijl van Groningen. Lezing op 4 Mijl clinic. Groningen.
Effect van lunchwalken op de gezondheid. Lezing UMCG, Groningen.
Hardlopen en gezondheid, de Marathon van Terschelling. Minisymposium voor huisartsen, Terschelling.
Instructie beweegcounselors Provincie Groningen in het kader van GSM. Groningen.
Overbelastingsletsels en ontwikkelingen. Netwerk fysiotherapie Groningen.
Handicap en sportgeneeskunde, Beatrixoord. Haren.

Onderwijsactiviteiten.

College 1ste jaars studenten geneeskunde RUG.
College 3de jaars studenten geneeskunde RUG.
Sportblessures in de huisartsen praktijk, Bewegingstweedaagse; vakgroep Huisartsengeneeskunde RUG.
Sportmedische problematiek in de huisartsenpraktijk. Vakgroep Huisartsengeneeskunde RUG.
Gastcollege Sport en bewegen, Hanzehogeschool.

Opleidingsactiviteiten.

Voorzitter Concilium Sportgeneeskunde.
Mede auteur Opleidingsplan Sportgeneeskunde 2012.
Hoofdopleider Sportgeneeskunde in de opleidingsregio Groningen.
Lid Centrale Opleidingscommissie (COC) UMCG.
Stagebegeleider differentiatiemodule Sportgeneeskunde voor huisartsen in opleiding.

Overige activiteiten.

Commissie Sportgeneeskunde College Geneeskundig Specialisme (CGS).
Taskforce erkenning sportgeneeskunde VSG.
Dagvoorzitter wetenschappelijk jaarcongres VSG.
Sessievoorzitter Hardlopen, wetenschappelijk jaarcongres VSG.
Kennistransfer Sportgeneeskunde Hardlopen.
Kenniscentrum Feet for life. HANN, NOM, Hanzehogeschool, Schutrups en het SMC UMCG.
Werkgroep beroepsprofiel Sportgeneeskunde 2012.
Medische Commissie Be Quick 1887.
Symposiumcommissie wetenschappelijk Sports Medicine Symposium UMCG.
Werkgroep deskundigheidsbevordering Sportgeneeskunde (WDS) van de VSG.
Commissie Wetenschap VSG.
Lid van de VSG, FIMS, ACSM, VSG, fellow UEMS, EFSMA.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2013

Bosker BH. Pitfalls in traditional and innovative hip replacement surgery
(prof SK Bulstra, dr CCPM Verheyen, dr HB Ettema)

Holwerda A. Work outcome in young adults with disabilities
(prof JJL van der Klink, prof JW Groothoff)

Mohseninejad L. Uncertainty in economic evaluations: implications for healthcare decisions (prof E Buskens, dr TL Feenstra)

Flach LR. A view beyond the horizon; a prospective cohort study on mental health and long-term disability (prof JJL van der Klink, prof JW Groothoff, dr S Brouwer)

Sobhani S. Rocker shoes for ankle and foot overuse injuries: a biomechanical and physiological evaluation (prof K Postema, prof ER van den Heuvel)

Pitel L. Sociocultural determinants, gender and health-related behaviour in adolescence (prof SA Reijneveld, dr JP van Dijk, dr A Madarasova-Geckova)

Majerníková M. Sef-rated health and mortality after kidney transplantation
(prof JW Groothoff, dr JP van Dijk, dr J Rosenberger, dr R Roland)

Verschuren J. Sexuality and limb amputation: perspectives of patients, partners and professionals (prof JHB Geertzen, prof PU Dijkstra, prof P Enzlin)

Riphagen-Dalhuisen J. Influenza vaccination of health care workers (prof E Hak)

Hasselt FM van. Improving the physical health of people with severe mental illness; the need for tailor made care and uniform evaluation of interventions
(prof AJM Loonen, prof MJ Postma, dr MJT Oud, dr PFM Krabbe)

Piening S. Communicating risk effectively
(prof FM Haaijer-Ruskamp, prof PA de Graeff, dr PGM Mol, dr SMJM Straus)

Siebelink MJ. The child as a donor; a multidisciplinary approach
(prof HBM van de Wiel, prof PF Roodbol)

Sidorenkov G. Predictive value of treatment quality indicators on outcomes in patients with diabetes (prof FM Haaijer-Ruskamp, prof D de Zeeuw)

Vu DH. Clinical pharmacology of tuberculosis drugs and tuberculosis control in developing world; the involvement of private pharmacy and the individualization of treatment using dried blood spot
(prof JRBJ Brouwers, prof DRA Uges, prof VH Le, prof DH Nguyen, dr JWC Alffenaar)

Sijtsma A. Physical activity and overweight in young children
(prof PJJ Sauer, prof RP Stolk, dr E Corpeleijn)

Rosicova K. Regional mortality in Slovakia: socioeconomic indicators and ethnicity
(prof JW Groothoff, dr JP van Dijk, dr A Madarasova-Geckova)

Bobakova D. Youth subcultures and problem behaviours in Slovakia: hip-hop, techno-scene, metal, punk,skinheads and Roma
(prof SA Reijneveld, dr JP van Dijk, dr A Madarasova-Geckova)

Arends I. Prevention of recurrent sickness absence in workers with common mental disorders (prof JJL van der Klink, prof U Bültmann)

Theunissen MHC. The early detection of psychosocial problems in children aged 0 to 6 years by Dutch preventive child healthcare; professionals and their tools
(prof SA Reijneveld, dr AGC Vogels)

Bragaru M. Sports and amputation (prof JHB Geertzen, prof PU Dijkstra, dr R Dekker)

Broesamle TC. Designing health care services using systems thinking; a theory, a method and their application in the Dutch community pharmacy
(prof JJ de Gier, prof JJ van der Werf)

Jong J de. Antibiotics use in children; pharmacoepidemiological, practical and environmental perpectives in the Netherlands
(prof LTW de Jong-van den Berg, dr TW de Vries)

Rettke HG & Geschwindner HM. Long-term outcomes in stroke rehabilitation patients and informal caregivers (prof WJA van den Heuvel)

Fortington LV. Enabling the elderly person with lower limb amputation through surgery, rehabilitation and long term care
(prof JHB Geertzen, prof PU Dijkstra, dr GM Rommers)

Lako IM. Depressive symptoms in patients with schizophrenia; count symptoms that count (prof K Taxis, prof D Wiersma)

Arnardottir AH. Regulatory benefit-risk assessment; different perspectives
(prof FM Haaijer-Ruskamp, prof PA de Graeff, dr PGM Mol, SMJM Straus)

Meijer A. The forest trough the trees; investigating depression in patients with cancer and patients with myocardial infarction using systematic reviews and meta-analytic techniques (prof P de Jonge, dr HJ Conradi, dr BD Thombs)

Kuchenbecker WKH. Obesity and female infertility
(prof JA Land, prof BHR Wolffenbuttel, dr A Hoek, dr H Groen)

Rozenbaum MH. Costs and effectiveness of extended vaccination strategies against pertussis and pneumococcal disease (prof MJ Postma, prof E Hak)

Kingma EM. Intelligence and functional somatic symptoms and syndromes
(prof JGM Rosmalen, prof J Ormel, prof P de Jonge)

Kedde JH. Sexual health of people with disability and chronic illness
(prof HBM van de Wiel, prof WCM Weijmar Schultz)

Horst PGJ ter. Clinical pharmacology of antidepressants during pregnancy
(prof B Wilffert, prof LTW de Jong-van den Berg)

Sinha R. Adjustment to amputation and artificial limg, and quality of life in lower limb amputees (prof WJA van den Heuvel, prof P Arokiasamy, dr JP van Dijk)

2012

Pechlivanoglou P. Applying and extending mixed-effects models in health in health economics and outcomes research (prof MP Postma, prof J Wieringa, dr HH Le)

Verboom CE. Depression and role functioning; their relation during adolescence and adulthood (prof J Ormel, prof WA Nolen, prof BWJH Penninx, dr JJ Sijtsema)

Benka J. Living with rheumatoid arthritis: do personal and social resources make a difference?
(prof JW Groothoff, prof JJL van der Klink, dr JP van Dijk, dr I Rajnicova)

Kalina O. Sexual risky behaviour among Slovak adolescents and young adults; social and psychological factors
(prof SA Reijneveld, dr JP van Dijk, dr A Madarasova-Geckova)

For more 2012 and earlier SHARE-theses see our website.

Sponsoren

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